VOL. XVII. 1910

TRANSACTIONS

OF THE

AMERICAN ELECTROCHEMICAL SOCIETY.

LIBRARY
Brigham Young University

COLLECTION ON GEOLOGY AND ENGINEERING

FROM DR. ALBERT CLARENCE BOYLE, JR.

CALL NO. [redacted]
V. 17

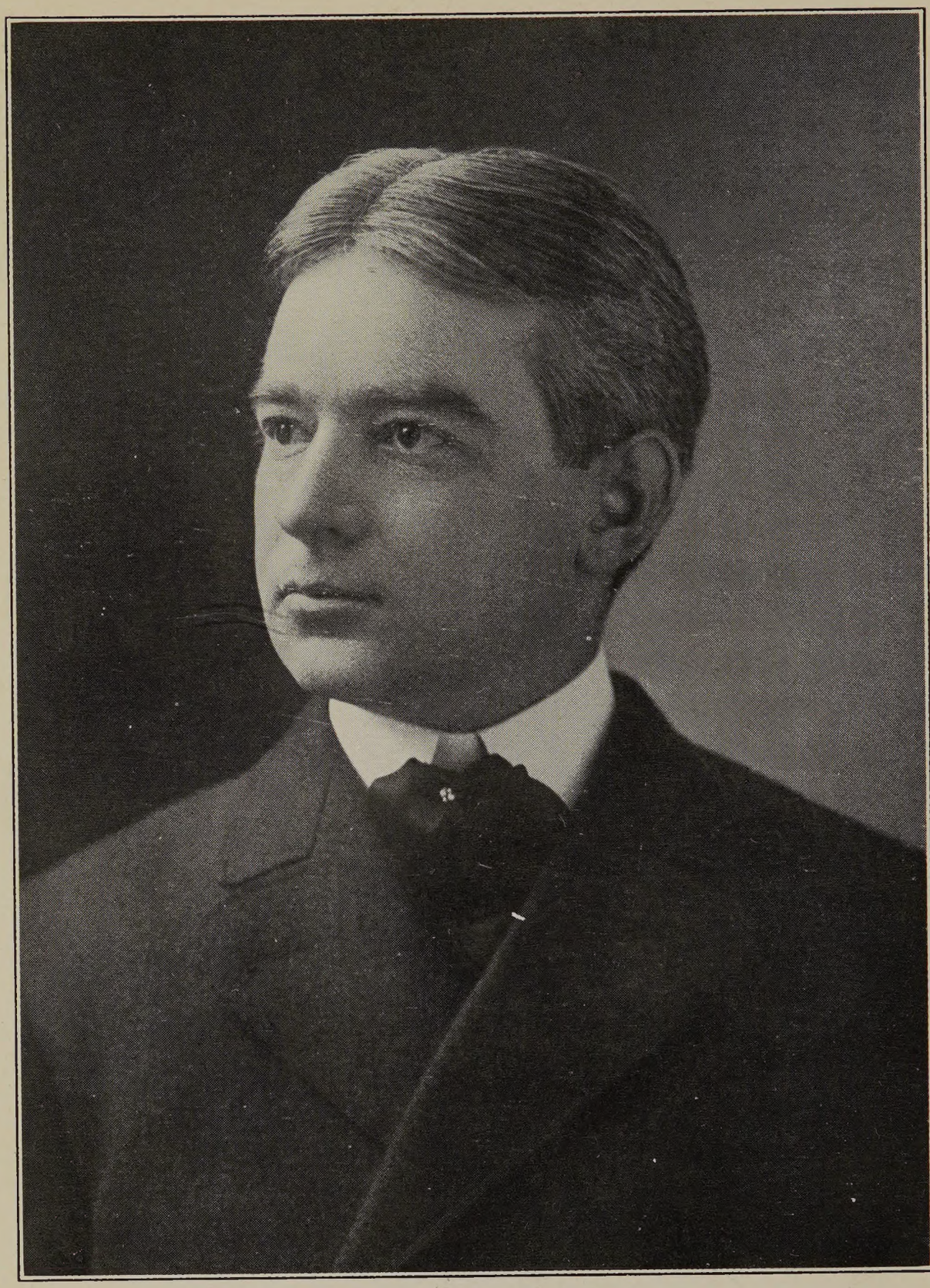
ACC. NO. 157547

PERIODICAL

Lizzie Davis

Sugar Loaf

Aug 16 - 10



Very truly yours,

Wm. H. Walker, Jr.

TP
250
.E542

TRANSACTIONS

OF THE

AMERICAN

ELECTROCHEMICAL SOCIETY

VOLUME XVII

157547

SEVENTEENTH GENERAL MEETING

PITTSBURGH, PA., MAY 4, 5, 6, 7, 1910.

PUBLISHED BY
THE AMERICAN ELECTROCHEMICAL SOCIETY
LEHIGH UNIVERSITY, SOUTH BETHLEHEM, PA.
1910

Copyright, 1910, by the American Electrochemical Society.

Permission to reprint parts of the *Transactions* is hereby granted to current periodicals, provided due credit is given.

This Society is not responsible for the statements and opinions advanced in papers or in discussion thereon.

One copy of each volume of the *Transactions* is supplied gratis to each member of the Society in good standing.

Prices of Volumes I to XVII (excepting Vols. III and X), to non-members $3.00 per copy, to members (extra copies) $2.50, to public libraries, colleges, scientific societies and journals, $2.00. Volume III, double above prices. Volume X, $2.00 to all purchasers. Prices are for volumes bound in cloth, and include delivery within the postal union.

Non-members may obtain complete sets at 25 percent discount on above prices; members may obtain the volumes necessary to complete their sets, at 25 percent reduction on above prices; public libraries, etc., purchasing complete sets to date, are allowed 10 percent reduction from above prices.

WARE BROS. COMPANY, PRINTERS
1010 ARCH ST., PHILA.

OFFICERS OF THE SOCIETY

PRESIDENT

WM. H. WALKER
Term Expires 1911.

PAST-PRESIDENTS

E. G. ACHESON
Term to 1911

L. H. BAEKELAND
Term to 1912

VICE-PRESIDENTS

F. J. TONE
CARL HERING
W. D. BANCROFT
Terms Expire 1911

E. F. ROEBER
S. S. SADTLER
L. KAHLENBERG
Terms Expire 1912

MANAGERS

F. A. J. FITZGERALD
A. von ISAKOVICS
S. A. TUCKER
Terms Expire 1911

EDW. R. TAYLOR
W. LASH MILLER
F. A. LIDBURY
Terms Expire 1912

C. F. BURGESS
C. P. TOWNSEND
W. R. WHITNEY
Terms Expire 1913

TREASURER

PEDRO G. SALOM
Term Expires 1911

SECRETARY

JOS. W. RICHARDS, Lehigh University, South Bethlehem, Pa.
Term Expires 1911

COMMITTEES

Executive Committee

Wm. H. Walker, Chairman — Jos. W. Richards, Secretary
L. H. Baekeland — Carl Hering — E. F. Roeber
S. A. Tucker — W. R. Whitney

Publication Committee

Jos. W. Richards, Chairman
W. H. Walker — Carl Hering — E. F. Roeber — H. E. Patten

Committee on Papers

H. E. Patten, Chairman

L. H. Baekeland	F. A. J. FitzGerald	E. F. Kern
Chas. Baskerville	F. C. Frary	A. B. Marvin
C. F. Burgess	L. Kahlenberg	J. W. Richards

C. Schleuderberg — W. R. Whitney

LOCAL SECTIONS OF THE SOCIETY

Wisconsin Section (*Madison, Wis.*)

PROF. C. F. BURGESS, Chairman, University of Wisconsin

DR. O. P. WATTS, Secretary, University of Wisconsin

Philadelphia Section

C. J. REED, Chairman

S. S. SADTLER, Secretary, 39 S. 10th Street, Philadelphia

New York Section

E. A. SPERRY, Chairman, Brooklyn

H. B. COHO, Secretary-Treasurer, New York City

Chicago Section

PROF. H. N. MCCOY, Chairman, University of Chicago

A. B. MARVIN, Secretary, Comm. Nat'l Bank Bldg., Chicago

MEMBERSHIP COMMITTEE

P. MCN. BENNIE, Chairman, Niagara Falls, N. Y.

L. I. BLAKE, Denver, Colo.
J. W. BROWN, Cleveland, Ohio.
H. B. COHO, New York City.
E. A. COLBY, Newark, N. J.
T. V. D'ORNELLAS, Lima, Peru.
J. B. DU FAUR, Mt. Morgan, Australia.
S. DUSHMAN, Toronto, Canada.
W. A. FERGUSON, Mexico City, Mexico.
F. C. FRARY, Minneapolis, Minn.
F. GIOLITTI, Turin, Italy.
J. S. GOLDBAUM, Philadelphia, Pa.
H. GOLDSCHMIDT, Essen, Germany.
F. J. IRGENS, Bergen, Norway.
G. R. KENDALL, Vancouver, B. C.
K. KISHI, Tokyo, Japan.
F. A. KJELLIN, Stockholm, Sweden.
M. LE BLANC, Leipzig, Germany.
A. LODYGUINE, St. Petersburg, Russia.
R. W. LOHMAN, San Francisco, Cal.
B. MAGNUS, Port Kembla, N. S. W.
C. A. MARIE, Paris, France.
A. B. MARVIN, Chicago, Ill.
I. J. MOLTKEHANSEN, Brussels, Belgium.
L. W. OHOLM, Helsingfors, Finland.
R. S. ORR, Pittsburgh, Pa.
H. PHILIPP, Perth Amboy, N. J.
K. B. QUINAN, Cape Colony, Africa.
H. RODMAN, East Pittsburgh, Pa.
S. S. SADTLER, Philadelphia, Pa.
H. SCHLUNDT, Columbia, Mo.
E. P. SCHOCH, Austin, Texas.
C. V. SMYTHE, Calcutta, India.
R. C. STICHT, Tasmania, Australia.
M. DEK. THOMPSON, Boston, Mass.
S. A. TUCKER, New York City.
O. P. WATTS, Madison, Wis.
W. R. WHITNEY, Schenectady, N. Y.
F. L. WILDER, Minas Geraes, Brazil.
T. A. WITHERSPOON, Washington, D. C.

ADVERTISING COMMITTEE

W. S. LANDIS, Chairman, South Bethlehem, Pa.

TABLE OF CONTENTS.

PAGE

Portrait of President W. H. Walker, Ph.D. ..... Frontispiece
Proceedings of the Seventeenth General Meeting 1
Annual Report of the Board of Directors 24
Annual Report of the Secretary 25
Annual Report of the Treasurer 29
List of Members and Guests in Attendance at Seventeenth Meeting 30
New Members, November, 1909 to May, 1910 33

ADDRESSES.

Science and Industry—President L. H. Baekeland 37
The Conservation and Utilization of Natural Sources of Power—John H. Finney 55
What Electrochemistry is Accomplishing—Joseph W. Richards 75

PAPERS.

Possibilities of Cheap Power in the Pittsburgh District—F. Crabtree ... 95
Induction Furnace Progress—T. Rowlands 103
A New Electric Steel Furnace—A. L. Queneau 131
On the Presence and Influence of Gases in Steel—P. L. T. Heroult 135
A Study in Furnace Conductors for Heavy Alternating Currents—K. C. Randall 139
Determination of the Constants of Materials for Furnace Electrodes—Carl Hering 151
Empirical Laws of Furnace Electrodes—Carl Hering 171
A New Radiation Pyrometer—C. E. Foster 223
Ductile Tungsten and Molybdenum—C. G. Fink 229
A New Method for the Electrolytic Winning and Refining of Metals—E. M. Chance 235
A New Process for the Treating of Cobalt-Nickel Ores Rich in Silver and Arsenic by Combined Melting and Electrolytic Operations—C. C. Cito 239
The Electrolytic Preparation of Magnesium—S. A. Tucker and F. L. Jouard 249
Electrodeposition of Lead from Perchlorate Baths—F. C. Mathers 261

PAGE

The Electrolytic Deposition of Platinum—II.—W. J. McCaughey and H. E. Patten 275
The Conductivity and Electrolysis of Cuprous Chloride Solutions—M. deK. Thompson and E. R. Hamilton 287
Comparison of Rapid Electrochemical Methods—I—The Determination of Copper—F. C. Frary and A. P. Peterson 295
A Rotating Graphite Anode—J. W. Turrentine 303
The Townsend Cell: Its Behavior Under Various Current Densities—H. K. Richardson and R. L. Patterson 311
The Whiting Electrolytic Cell for the Production of Caustic Alkali and Chlorine—J. Whiting 327
Some Characteristics of the Modern Dry Cell—D. L. Ordway 341
Electrochemical Potentials and Electrical Conductivity of Aluminium-Calcium Alloys—J. M. Breckenridge 367
The Electrolytic Reduction of Nitric Acid—III—H. E. Patten and W. J. McCaughey 377
The Effect of Moisture and of Solutions Upon the Electric Conductivity of Soils—R. O. E. Davis 391
The Separation of Oil from Condenser Water by Electrolysis—H. M. Goodwin and R. Ellis 405
Index 425
Advertisements .....

VOLUME XVII. 1910.

TRANSACTIONS

OF THE

AMERICAN ELECTROCHEMICAL SOCIETY

PROCEEDINGS

CONDENSED MINUTES OF THE SEVENTEENTH GENERAL MEETING OF THE SOCIETY, HELD IN PITTSBURGH, PA., MAY 4, 5, 6, 7, 1910.

Number of members registered, 192; guests, 253; total, 445.

PROCEEDINGS OF WEDNESDAY, MAY 4th.

Registration of members and guests began at 9.00 A. M., at the hotel headquarters, Fort Pitt Hotel.

At 1.30 P. M. an excursion party of, approximately, 150 persons left by special electric cars (furnished gratis by the Pittsburgh Railroad Companies) for the United States Geological Survey Testing Station, at Fortieth and Butler Streets.. The Technologic Branch of the United States Geological Survey is installed in the old arsenal buildings, occupying a large tract of ground, and the practical work of this testing station is supervised in general by the Director, Mr. George Otis Smith, but is in immediate charge of Dr. J. A. Holmes, Chief Technologist, assisted by Mr. H. M. Wilson, Assistant Chief Technologist, Mr. J. C. Roberts, Assistant Chief Engineer, together with the engineers and chemists in immediate charge of the different sections engaged upon separate physical and mechanical problems.

The program of special tests for the entertainment of the visitors included:

Part I. Demonstration of explosion of a permissible explosive in the large dust and explosion gallery.

Part II. Effect of explosion of a charge of black blasting powder, igniting the coal dust in the explosion gallery.

Part III. Demonstration of rescue apparatus in a room filled with dangerous gases.

Part IV. Demonstration of force of an explosion by the Ballistic pendulum.

Part V. Demonstration of properties of an explosive mixture of gas and air upon a single-gauze and double-gauze safety lamp, at different velocities of gas current.

Part VI. Testing of incandescent carbon lamp films in various gaseous atmospheres.

Part VII. Work test of fire-brick in kilns in service, up to 1300° C.

Part VIII. Mechanical tests of steel cable on 300-ton machine.

Following this the visitors were taken through the various physical and chemical laboratories, and given full opportunity to inspect the operation of calorimeters, pyrometers, laboratory electric furnaces, etc.

A considerable number of the expert chemists and physicists connected with the station are members of the Society, and joined with the rest of the staff in escorting the visitors and explaining the tests. The lucid explanations of the physical and mechanical principles given by the gentlemen in charge were highly appreciated by the visiting members and guests.

A reception to the visiting members, guests and ladies was held by the Officers of the Society and the Local Committee in the English Room of the Fort Pitt Hotel in the evening of this day, giving early opportunity for those in attendance to become personally acquainted and enjoy social recreation.

SESSIONS OF MAY 5th.

The Board of Directors met at 9.00 A. M. at the Fort Pitt Hotel, adjourning at 10.00 A. M.

The morning session of the Society was called to order at 10.00 A. M. in the English Room of the Fort Pitt Hotel, President L. H. Baekeland in the Chair.

Mr. Chas. F. Scott, Chairman of the Local Committee, greeted the Society on behalf of the local members, and introduced Mr.

E. K. Morse, president of the Engineers' Society of Western Pennsylvania, who welcomed the Society to Pittsburgh as follows:

"Mr. Chairman, Ladies and Gentlemen:

"I am glad to see by the register this morning that so many of you have found your way to Pittsburgh. It is a city that is but little advertised (laughter); it has not been advertised any lately, although we do have a resort on the other side of the river called the West Pen—the penitentiary—that is very popular, with prospect of a greater attendance in the near future. (Laughter.)

I am acquainted with some of your members. You are young and vigorous, entering upon a new subject, and if I had ten years of my life to live over again I would like to join you. The subject that I want to impress upon you at this time is the one that made Roosevelt's administration what it was and is; what will go down in history. The "Big Stick" will be forgotten, but that which will stay with this country, that which posterity will reap the benefits of, is Conservation of our Resources, both State and National.

"You do not have to go 50 miles from where we are now seated in this hall to find blast furnaces that were built on the basis of 800 tons each per day, were paid for on that basis, have been operated with strenuousness, that are intended for 800-ton furnaces, and have not averaged 400. There is a field for you. The subjects that you are taking up are ones that have been uppermost in my mind, but it is too late for me to take hold of them as I would like to. Eighty to 90 percent of the tonnage of the large steel mills in this vicinity ship their finished material west. The center of gravity has left Pittsburgh, and is no longer coming up the Monongahela River. Our tonnage has been going west, and has already reached the Lakes, and we must be on the alert. We have got to depend upon you, gentlemen, to help us out or else lose our supremacy in the steel market. There is no use to deny it. In the summer of 1897 Elliot Holbrook, a railroad superintendent, J. W. Patterson, an engineer, and myself, after laborious work, figured out the tonnage per actual bills of lading, in and out of Pittsburgh. It amounted to 35,000,000, and we didn't have the nerve to publish it. In 1907 the tonnage had gained

three and one-half times the tonnage of 1897, and that does not include the millions upon millions of tons that are handled by such firms as Carnegie's and Jones & Laughlin Steel Company, that have their own organized railroad systems in their respective mill yards.

"I remember in my own father's sawmill when we sawed up thousands upon thousands of feet of curly and bird's-eye maple for the top board on board fences. No wonder that in the last ten years I have devoted all the time I possibly could to saving timber from going into the foundations of the bridge piers that are built in the river, and have saved millions of feet by substituting other construction. I want to atone for my sins. We depend upon you gentlemen to help out the old sinners, and I am one of the greatest. That field is open for you.

"Today Pittsburgh is interested in some of the new enterprises. It has not been attempted in this country before to my knowledge on the scale it is being carried out here; it is known locally as the Pittsburgh Flood Commission. We are today making accurate surveys at the headwaters of the Allegheny and Monongahela Rivers, in order to accurately determine where we can put in impounding dams for the prime purpose of holding back the crest of the floods. A second work is the protecting of the city by a retaining wall, or other methods. The work is going ahead, and I do not feel I am disclosing any of the State secrets of the local engineers of this city, who are giving their time gratuitously, by saying that we can already put our fingers on splendid sites for many reservoirs in the vicinity of the headwaters and of Pittsburgh that will have a rain-shed of from 50 to several hundred square miles each. We depend upon you gentlemen to attach electricity to these reservoir sites and turn our mad, destructive floods into supplies of power—it will be done. The day is too late when we can build great dams across either the Allegheny or Monongahela Rivers. Railroads are located along the banks of these rivers, but these rivers are like the trunk of a great tree, with innumerable branches, and reservoirs and dams can be built in the branches. I feel, as a member of the Engineers' Committee of the Flood Commission, like saying what I believe our report will be; we hope to make it so imperative that the City, Commonwealth and the United States Government will step in

and take up the work where we stop and go right on with the work of conservation. Think of the amount of money that rushes down these two rivers in the shape of power during a flood. At 2 o'clock A. M., on the 15th of March, 1907, I stood down at the corner of Market and Liberty Avenues studying the flood. The lower parts of our city streets were out of sight and navigable by boats. Our direct losses in the City of Pittsburgh in two days' damage done by the destruction of goods and materials that had to be replaced by new goods was $4,000,000. That would build part of a retaining wall around our city. These are subjects for you gentlemen to think about. They are in the line of conservation.

"I have seen the whole coal field of this section absolutely exhausted in my short span of life. Railroads that were built to connect those coal fields are now occupied by corn fields, literally plowed under.

"On behalf of the engineers of the city of Pittsburgh I wish to extend to you the most cordial invitation I can. The new quarters of the Engineers' Society of Western Pennsylvania, on the 25th floor of the new Oliver Building, will be in shape, probably, this afternoon, and we hope to welcome many of you in our new home quarters. We are not only glad to have you in our midst, but we are glad to show you what has been done here in a little over fifty years' time. You can see what the engineers have done in fifty years.

"Permit me to extend to you, metaphorically, the keys of the City of Pittsburgh. I am not the Mayor, but when the Engineers of the City of Pittsburgh extend to you their welcome, it means the whole thing." (Applause.)

At the close of Mr. Morse's address of welcome, the Chairman called on Mr. Chas. F. Scott, the energetic Chairman of the Local Committee, who responded as follows:

"Ladies and Gentlemen:

"At one of its earliest meetings our committee laid out a program for this convention, but as we were about to adjourn the thought struck us that the electrochemists who were coming to Pittsburgh would apparently meet quietly in a hotel, and visit

a few industrial plants, without coming in contact with the people of Pittsburgh, and that Pittsburghers would not know they had been here until they saw a little notice in the papers after the meeting was over. So we decided to change the program, and to let our visitors see the city and meet the people of Pittsburgh. We also wanted Pittsburgh people to be awakened to the possibilities and necessities of the application of science to its industries, and to see what this Society is, and get some insight into the new and modern methods for which it stands.

"For the past twenty years, as Mr. Morse has intimated, the problem in this district has been one of output, one of quantity, and, as he also intimated, the problem of the future is to be one of quality, one of economy. Pittsburgh needs the scientific methods which you can bring to us. So, in laying out our final program we have enlarged its scope, and we have told Pittsburgh engineers and those connected with our industries that you are coming, and have invited them to meet with you. Instead of confining our meetings to a hotel, we have decided that we will do the biggest thing we can, by opening up Carnegie Music Hall for one meeting and inviting everybody in the city interested to learn something about electrochemistry.

"We have laid out a program for you as visitors, arranging details as best we could, not knowing just how many will be here and just what you may prefer to do. We have explained the plans in a little hand-book, which will possibly be of considerable use to you. We hope you will enter into the spirit of the occasion, and join with us in trying to make this a good meeting and in getting the most out of it. To the Pittsburghers who are here I wish to say we are glad to see you here this morning, joining with the committee in its welcome, and we hope you will continue to come and bring your friends during the week.

"The Local Committee joins with the President of the Engineers' Society in opening up the city to the Society, and in extending the opportunity of meeting our people and visiting some of our industries." (Applause.)

At the close of Mr. Scott's remarks the regular business of the session was taken up.

BUSINESS MEETING OF THE SOCIETY.

The reading of the Minutes of the Sixteenth General Meeting was dispensed with, and they were approved as published in the Transactions, Volume XVI.

The report of the Board of Directors, including those of the Secretary and Treasurer, was read by the Secretary and accepted for publication in the proceedings of the meeting, to which it is herewith appended.

The Committee on Papers reported as the result of its activity the obtaining of 19 papers for the Sixteenth General Meeting, which are published in the Transactions, Volume XVI, and the procuring of 29 addresses and other communications for the present Seventeenth General Meeting.

The Publication Committee reported the publication in 1909 under its direction of the proceedings of the Sixteenth General Meeting in the Transactions, Volume XVI, containing 479 pages, and that the Transactions, Volume XVII, containing the report of this present meeting, will be of about equal size. It will be the intention of the committee to complete the publication of this volume at the earliest possible moment consistent with proper editing and printing.

Mr. A. von Isakovics, the retiring Chairman of the Membership Committee, took the floor and stated that the membership of the Society had doubled in the three years during which he had charge of the work. He ascribed this mostly to the fact that many men in many countries were willing and even anxious to join the Society, as soon as they knew of its work and what it stood for, and that all that was needed was for the Society to let them know, in a proper way, of its existence. (Applause.)

Before presenting the report of the annual election, the Secretary read an action of the Board of Directors, adopted at its last meeting, to the following effect:

"That, upon the urgent request of Dr. W. R. Whitney to be relieved from the responsibility of serving the Society as President during the coming year, if elected thereto, and recognizing under the circumstances the reasonableness of this request, the Board of Directors granted the petition and declared Dr. Whitney ineligible to election as president for the coming year."

The report of the annual election for president, three vice-

presidents, three managers, treasurer and secretary was then, in the absence of the tellers, opened by the Secretary and read as follows:

REPORT OF THE TELLERS OF ELECTION.

To the American Electrochemical Society:

GENTLEMEN: Following is the result of the count of ballots for officers of the American Electrochemical Society:

For President—W. R. Whitney, 199; W. H. Walker, 71; C. A. Doremus, 18; E. R. Taylor, 7.

For Vice-Presidents—E. F. Roeber, 224; S. S. Sadtler, 140; L. Kahlenberg, 121; E. R. Taylor, 114; C. F. Burgess, 75; A. von Isakovics, 65; F. A. J. FitzGerald, 39; C. F. Chandler, 32; W. L. Miller, 22; S. A. Tucker, 18; W. H. Walker, 3; W. R. Whitney, 1.

For Managers—C. F. Burgess, 176; C. P. Townsend, 134; W. R. Whitney, 73; F. A. Lidbury, 71; A. D. Little, 60; H. R. Carveth, 59; C. Baskerville, 54; C. Hering, 50; M. Toch, 49; F. J. Tone, 36; H. S. Carhart, 34; H. Howard, 30; C. A. Doremus, 29.

For Treasurer—Pedro G. Salom, 287.

For Secretary—Jos. W. Richards, 293; C. A. Doremus, 1.

Respectfully submitted,

BARRY MACNUTT, *Chairman.*
S. S. SEYFERT,
W. S. LANDIS.

South Bethlehem, Pa.,
May 3, 1910.

The Chairman then stated that, in accordance with the Report of the Tellers and the action of the Board of Directors, he declared as elected the following:

President (for one year)—W. H. Walker.

Vice-Presidents (for two years)—E. F. Roeber, S. S. Sadtler, L. Kahlenberg.

Managers (for three years)—C. F. Burgess, C. P. Townsend, W. R. Whitney.

Treasurer (for one year)—Pedro G. Salom.

Secretary (for one year)—Jos. W. Richards.

[On May 26th, the Board of Directors elected F. A. Lidbury as Manager, to fill the un-expired term of W. H. Walker, vacant because of the latter's election as president.]

President-elect Walker was given the floor, and spoke as follows:

"Fellow Members of the Electrochemical Society:

"I am sure I appreciate very highly, indeed, the honor of this election, although I regret, as I know you all regret, that Dr. Whitney was not able to accept the position at this time. I did not know of his having withdrawn, and this honor has come as a very agreeable surprise, as well as somewhat of a shock.

In what little official life I have had I have been unfortunate, in that I have not been able to select my predecessors; and this time it is especially true. We have had a long line of presidents of the Electrochemical Society who have been so efficient that it is difficult for anyone who succeeds them to fully reach the high standards that they have set. But we are very fortunate, indeed, that our Secretary has consented to accept the office for another year, and with him at the helm I cannot do other than succeed. All I can promise, therefore, is to give him all the support I can, and to work for the good of the Society." (Applause.)

The business part of the session being concluded, the reading and discussion of papers was taken up as follows:

Papers by Mr. Carl Hering were presented by Mr. Hering in abstract and discussed. A paper announced on the program by Mr. C. J. Reed was withdrawn, a note being read from Mr. Reed to the effect that, "As the paper was based upon a misunderstanding, the clearing up of this has rendered it unnecessary." Further papers were read by Mr. K. C. Randall, A. L. J. Queneau, P. L. T. Heroult, S. A. Tucker and F. Jouard, and discussed, as printed in the Transactions.

The afternoon of this day was devoted to excursions to industrial plants in the Pittsburgh district, of which the choice was offered as follows:*

* The following descriptions of industrial plants are abridged from the fine "Handbook" gotten up by the Local Committee.

ISABELLA FURNACES OF CARNEGIE STEEL CO.

Gayley Dry Blast Plant, Etna, Pa.

Guides: Messrs. Bruce Warner and R. Taylor.

This was the first blast furnace plant in the world to be supplied with artificially dried blast. There are located here three modern blast furnaces of 500 tons' capacity each, producing iron, spiegel and ferro-manganese.

The Gayley Dry Blast Furnace plant has a capacity of 40,000 cubic feet (1,200 cubic meters) air per minute, with a maximum temperature of the outside air of 90° F. (32° C.), and maximum moisture in the outside air of 8.5 grains per cubic foot (19.3 grams per cubic meter). The plant contains the following apparatus:

One hundred thousand lineal feet (30,500 meters) of 2-inch (5-cm.) pipe, giving an exterior surface of 62,000 square feet (5,600 square meters).

Twenty-five coils of submerged double pipe, forming the brine cooler.

Thirty-seven coils forming an atmospheric-type ammonia condenser.

Two Duplex brine pumps.

Two Duplex vertical single-acting ammonia compressors.

Ten thousand pounds (4,500 kg.) anhydrous ammonia and 40,000 gallons (140,000 liters) calcium chloride are used in charging the plant, which requires an indicated horsepower to operate of 412. The ice accumulating on the coils is thawed off every fourth day. The temperature of the air is reduced to 33° F. (0.5° C.), and the moisture to from 1¾ to 2 grains per cubic foot (4 to 4.5 grams per cubic meter). The moisture thus removed from the air blast amounts to 6,000 gallons (25 tons) during a 24-hour period. In the winter season the moisture in the blast is frequently less than one grain per cubic foot (2.3 grams per cubic meter), and consequently the actual amount of water removed is very small.

Estimated saving by use of dry blast, 360 pounds (164 kg.) of coke per ton of iron, and an increase in tonnage of 11½ percent.

PARK WORKS OF CRUCIBLE STEEL CO. OF AMERICA.

Guide: Mr. G. S. Page.

The Park Works manufactures various grades of crucible steel, as well as many special grades of acid and basic open-hearth steel.

It is the largest individual works belonging to the Crucible Steel Company of America and, when in full operation, employs about 2,500 men. Its average production of finished steel amounts to 140,000 to 150,000 tons per year.

Natural gas is used for fuel in melting both crucible and open-hearth steel and also largely for re-heating purposes, while coal is used for balance of the re-heating and for steam power. Natural gas is piped from West Virginia. Coal is received at the works by both rail and river, about one-half the supply coming each way.

Raw materials, so far as possible, are received in yards served by overhead electric traveling cranes, where electro magnets are used when convenient for handling.

The crucible melting department consists of 12 Siemens regenerative furnaces, ranging from 24 pots to 48 pots each.

The maximum melting capacity in crucible steel ingots is about 3,000 pots of 100 pounds (45 kg.) each in 24 hours, or about 150 net tons (136 metric tons). In tonnage output, this crucible melting department is the largest in America, and is only rivaled by that of Krupp aboard.

The open-hearth department consists of 8 furnaces, 3 "acid" and 5 "basic," ranging in capacity from 18 to 50 tons each. In this department effort has been directed toward the production of the finer grades of open-hearth steel and to specialties, rather than toward large tonnage. About 30 steam hammers and 20 trains of rolls are used in the production of the finished product. The company manufactures all its graphite crucibles with graphite brought from Ceylon and clay brought from Germany. At this works are made all the celebrated brands of the "Black Diamond" tool steel, some of which have been on the market for nearly fifty years; the Park "Extra," "Special" and "Silver" brands are also made here. Among the high speed steels, the "Rex A" and "Rex AA" brands are produced at this works. Protective shields for field guns for the United States Army, which require plates 0.15 inch (4 mm.) thick to stand impact of cupro-nickel jacketed bullet from an army rifle with 2,140 feet (660 meters) per second muzzle-velocity at range of 50 yards (47 meters), without the plate showing any signs of crack, and only a limited amount of "bulge," are also made at this works.

Alloy steels in which tungsten, chromium, nickel, vanadium, silicon, manganese, titanium and other metals are used in varying combinations and proportions, are produced extensively at this plant, as are also the composite steels made up of layers of hard and soft steel, such as 5-ply safe steel, jail bar, soft center and hard center.

JONES & LAUGHLIN STEEL COMPANY.

Guide: Mr. H. H. Laughlin.

On the north side of the river are located the coke ovens, which receive coal from the company's mines by boat. This coke feeds six blast furnaces, which deliver hot metal to the open-hearth and Bessemer departments of the South Side Works over the company's hot-metal bridge. Adjacent to this is a second bridge for general freight service. Further down the river are the structural shops, chain works, spike works and plate mills.

The South Side open-hearth plant includes nine 200-ton Talbot continuous furnaces, and seven stationary furnaces of approximately 50 tons' capacity each. These, with the three 10-gross-ton converters, supply through the various blooming and billet mills, the 17 finishing mills, hammer-shops, foundries, etc., which, with the auxiliary mills and shops of the North Side, furnish a great variety of products, among which are structural shapes, steel bars, billets, light rails and fittings, plates, sheets, concrete bars, spikes, rivets, chains, coupling links and pins, forgings, steel castings, cold-rolled shafting and shapes, cold-drawn shafting, finger

bars, coupling hangers, pillow blocks and pulleys—in fact, almost everything in the list of steel products, from a small spike or rivet to a "steel skeleton sky-scraper," or a cotton mill complete in all its details.

Perhaps the most interesting feature in this plant to the electrochemical engineer is the Talbot open-hearth department, which is said to be the finest of its kind in this country. A brief description of the process is given below.

The Talbot furnace was devised by Benjamin Talbot, of England. The furnaces now in operation here are of 200 and 250 tons' capacity. They are called continuous because they are never entirely empty during a run. The furnaces may be termed basic lined tilting open-hearth continuous furnaces.

When starting the furnace the first of the week, the charge consists of cold pig-iron of low silicon content, steel scrap, burnt lime or limestone, the same as used in a stationary furnace. When the bath is in the liquid state, molten pig-iron of low silicon content is taken from the mixer and added to the bath, an oxidizing slag being made by the addition of roll-scale before the above metal addition. These different operations of adding roll-scale, lime and metal are continuous until the bath contains 200 tons or more, when the slag and bath are brought into condition for tapping, after which 60 to 80 tons are poured off into a ladle, where the proper de-oxidizing alloys are added and the steel is teemed into moulds.

The important part of the operation is the addition of roll-scale and lime, as all the metalloids in the iron are to be oxidized chiefly by the oxygen brought in by the addition of roll scale. It becomes necessary to have a good grade of scale, one having a low content of silica, phosphorus and sulphur. Suffice to say here that advantage is taken of the affinity of the metalloids for oxygen, and for this reason the addition of scale is made. The scale, which contains 70 percent iron, is added to the bath along with enough calcined lime to take care of the silica which will come from the oxidation of silicon from the metal added; also to hold the phosphorus, which is oxidized to phosphoric acid and enters the slag as calcium phosphate.

It has been determined by figures and by practical experience that the required amount of scale to add in order to get the correct amount of oxygen to oxidize the metalloids is about 21 to 24 percent of the metal charged; and the lime from 6 to 8 percent, according to the composition of the lime and scale, when using iron of the following composition:

Silicon	1.00	percent
Phosphorus	0.2 to 0.25	"
Manganese	1.0 to 1.40	"
Sulphur	0.03	"
Total Carbon	3.80	"

The scale and lime should have time to form a slag before the addition of metal, if good results are to be obtained. The removal of phosphorus from metal to the slag requires its oxidation and conversion into phosphoric acid. A relatively low temperature favors this removal. It is for this reason that lime must be present at the proper time and in the proper amount in order that the phosphorus may unite with the lime to form calcium phosphate, as this compound is more stable than any other compound of phosphorus formed in the furnace. Suffice to say that the slag must be in the proper condition if good results are to be obtained.

As stated in the beginning, scale and lime are added to de-carbonize, de-siliconize and de-phosphorize the iron in the furnace. After the scale has been charged in the furnace for about one hour, 30 to 60 tons of mixer-iron is poured through a trough into the furnace. The reaction takes place immediately, and is somewhat like a Bessemer blow during the elimination of carbon, inasmuch as a large volume of carbonic oxide gas is driven off. The reactions between the slag and metalloids are as follows:

$$\begin{aligned} Fe_3O_4 + 4C &= 4CO + 3Fe \\ Fe_3O_4 + 4Mn &= 4MnO + 3Fe \\ Fe_3O_4 + 2Si &= 2SiO_2 + 3Fe \\ 5Fe_3O_4 + 8P &= 4P_2O_5 + 15Fe \end{aligned}$$

When the iron oxide of the slag reacts upon the bath containing silicon, phosphorus and manganese, they are in turn oxidized, to silica, phosphoric acid, and manganese oxide, which enter the slag. The carbon is oxidized to carbonic oxide.

As already shown, the reaction between the impurities and the oxide of iron charged reduces a certain amount of iron, which is taken up by the bath. As the amount of iron reduced is greater than that of the amount of impurities oxidized, there is a net gain in product amounting up to 12 percent of the pig-iron, depending, of course, upon the amount of impurities it contained. Figuring on the total amount of iron charged, that is, pig, scale, etc., the steel produced amounts to 85 percent. As the metal is tapped into the ladle, FeSi and FeMn are added. The reason for adding this silicon and manganese is to produce solidity of ingot structure by removing the gas-forming constituents of the metal. An easily-fusible slag is formed by the silica and manganese oxide, which, being lighter than the molten metal, rise to the top, and the metal will cease bubbling and pour quiet or "dead," thus producing solid ingots. FeSi and FeMn also have the property of eliminating oxides which are due to the over-oxidation of the metal. The efficiency of this addition depends upon the condition of the slag and metal, and also upon its temperature. The steel is then teemed into the moulds, which are taken to the strippers, after which the ingots are placed in soaking pits and re-heated and made ready for rolling.

PENNSYLVANIA SMELTING COMPANY, CARNEGIE, PA.

Guide: Professor Fred. Crabtree.

Among the most interesting portions of this plant are two water-jacketed blast furnaces for smelting the ore, reverberatory matte-roasting furnaces, reverberatory softening (refining) furnaces, and desilverizing kettles for separating silver and gold from the lead bullion; zinc distillation furnaces for separating zinc from zinc-silver crusts, and cupelling furnaces for refining the silver and gold; also beehive ovens for making the coke required by the blast furnaces.

A considerable variety of ores and of products containing lead and silver are smelted here; ores from the Cobalt district in Canada, the Coeur d'Alene district in Idaho, the Middle West and other districts; and among the products are high-grade litharge, refined lead, antimonial (hard) lead, silver, matte and speiss.

UNIVERSAL PORTLAND CEMENT COMPANY, UNIVERSAL, PA.

Guide: Mr. William Kinney.

The original plant, with a capacity of 4,500 barrels of cement a day, was put into operation December 31, 1907. The ground was broken for the addition with a capacity of 5,500 barrels a day, January 15, 1909. The mill is now in full operation, with a productive capacity of 10,000 barrels a day and a storage capacity of about 650,000 barrels. This large storage capacity insures well-aged cement, and, owing to the facilities for packing, permits of prompt shipment.

The entire plant is operated by electrical power. Alternating current is generated at 6,600 volts by generators driven by gas engines supplied with waste gases from the Carrie blast furnaces of the Carnegie Steel Company. The current is stepped up to 22,000 volts and transmitted over a high-tension line to the plant, where it is stepped down to 440, the operating voltage.

The raw materials used in the manufacture of Universal Portland cement are limestone and granulated blast furnace slag, the latter being the product of the Bessemer furnaces of the Carnegie Steel Company. Large bins approached by elevated tracks at one end of the raw material mill provide the storage room for the raw material. From these bins the limestone is fed directly into gyratory crushers, which prepare it for the dryers, into which the stone then enters. The slag is also fed into separate dryers, all of which are maintained at a sufficiently high temperature to drive off the moisture. After passing through the dryers, each of the raw materials is conveyed into separate Ball and Williams mills, where rolling and impact reduces them to extreme fineness. The two materials are then carried to separate hoppers, from which they are drawn off and properly proportioned by electrically-operated weighing devices. The mixture of slag and limestone, already a powder, is then

passed into tube mills, where flint pebbles rolling in a steel drum thoroughly mix it and complete the process of pulverization.

The next step is the calcination of this raw mixture in rotary kilns. Leaving the rotary kilns, the clinker, produced by the burning, is dropped into storage pits, where it is cooled and cured. Electrically-operated cranes then carry the clinker to the finishing mill, where it is passed through jaw crushers to Kent mills and then over Newyago separators. After the addition of a certain quantity of gypsum, which is done by means of an automatic device, the material again passes through tube mills similar to those used in finishing the raw material. Being now ground to a specific degree of fineness, the cement passes on to a belt conveyor and is distributed into the various bins of the storage house. The cement, in passing from the finishing mill into the storage house, is automatically sampled, from which samples the various tests for quality are made in the laboratory.

PITTSBURGH REINFORCED BRAZING AND MACHINE COMPANY, PITTSBURGH, PA.

Guide: Mr. H. K. Hitchcock.

This company makes a specialty of repairing broken parts of complicated and expensive machinery, such as automobile parts, printing presses and other high-grade machines, by either brazing, brazing with reinforcements across the breaks, or by welding the broken parts together, the exact method used depending upon the material and character of the break. The heating is done in portable furnaces by gas, oil or oxy-acetylene burners. The materials operated on are generally cast iron, aluminum, steel and brass. After the pieces have been thoroughly brazed or welded together, they are given the necessary machining and then tested to see that the repair is perfect.

NERNST LAMP COMPANY, PITTSBURGH, PA.

Guide: Mr. Max Harris.

In the chemical laboratory was shown the process necessary for the reduction and refinement of the material from which the glower or light-giving element of the Nernst lamp is made. The ores used in the manufacture of this glower are brought in their crude state from the company's mines in Texas to the laboratory, where they are subjected to various operations and processes, until chemically pure material is obtained.

The process of squirting the glower paste was shown. This paste is mixed in a specially designed kneading machine until the dough becomes of a proper consistency, when it is placed in guns, and squirted into rods, tubes and other forms, depending upon the capacity desired. After being dried, it is cut in suitable lengths and placed in platinum tubes and

roasted at high temperatures. The finishing operations of applying terminals, sorting, etc., were shown.

The manufacture of the platinum heater was shown and described. The material for this heater is prepared and squirted in much the same manner as that of the glower. The various operations of treating and flashing carbon filaments to make the new mineral heater were also shown.

In the department where the ballasts are made, the entire process through which this part of the lamp must pass was seen.

The making of the mechanical parts were described and the assembling of the entire lamp shown.

The evening session was held in the English Room of the Fort Pitt Hotel, commencing at 8.00 o'clock with the presidential address, "Science and Industry," by Dr. L. H. Baekeland, the retiring President. This was followed by papers of F. Crabtree, T. Rowlands, C. G. Fink, C. Cito and C. E. Foster.

PROCEEDINGS OF FRIDAY, MAY 6th.

This entire day was devoted to an excursion, in which 257 members and guests participated, leaving Pittsburgh early on a special train which was at the disposition of the Society for the entire day. The following plants were visited:

ALLEGHENY PLATE GLASS COMPANY, GLASSMERE, PA.

This is a modern, up-to-date plant, which produces about 4,000,000 square feet (367,000 square meters) of polished plate glass per year.

The casting hall was shown, where the glass is melted and refined in pots or crucibles, each holding just enough glass to cast one plate, the same being placed in regenerative gas furnaces.

These pots are taken from the furnaces by electric cranes and "teemed" or poured in front of a cast-iron roller on a casting table, where the plate is rolled into shape.

The plate is then pushed in zig-zag fashion through a series of ovens having decreasing temperatures, and finally loaded upon iron rods, which pass it by a "step-along" motion from the hot to the cold end of a long tunnel or run-way, from which it emerges cooled to the temperature of the air and properly annealed.

Here the plates are trimmed or squared-up and secured to the top of cast-iron tables by being embedded in plaster of paris. These tables are then pushed into a machine, and by means of cast-iron runners and coarse sand, the plates are ground to a true plane, after which their surfaces are given a fine, smooth finish by the application of finer and finer abrasives, carefully graded, and occasionally washing off the coarser material.

THE ELECTROCHEMICAL INVASION OF PITTSBURGH—HOMESTEAD, MAY 6, 1910

These tables are then removed, thoroughly cleaned, and the joints filled with new plaster, when they are placed in the polishers and the surface polished by means of felt runners or blocks and the application of rouge.

The tables are then withdrawn, the plates lifted, turned over, and the other side treated in like manner, when the glass is again removed, taken to the warehouse, cut to size and shipped.

WESTINGHOUSE ELECTRIC AND MANUFACTURING CO., EAST PITTSBURGH, PA.

The company was established in 1886, starting with a force of some 200 men. The original works were situated in Pittsburgh, at Garrison Way and Fayette Street, two squares from the Fort Pitt Hotel. The shops were removed to East Pittsburgh in 1894 and 1895. They then had a floor space of about 12 acres and gave employment to some 3,000 persons. Increase of business warranted the extension of the works in 1899 and from year to year thereafter, until the total floor space now is a little over 53 acres, covering about 29 acres of land.

The works at present employ nearly 10,000 men and 2,000 girls, and have an office force of approximately 2,500.

The monthly output represents about $3,000,000, and consists of electrical apparatus of every kind, including generators of all types, ranging from 1 to 20,000 kilowatts; motors of all types, ranging from 10 watts to 10,000 kilowatts; electric locomotives, lightning arresters, switchboards, oil and air-break switches, circuit-breakers, electric household apparatus, such as flat irons, toasters, radiators and chafing dishes. In fact, it may be said that this company manufactures almost everything electrical.

The greater part of the power used in the works is generated by four Westinghouse-Parsons steam turbines, aggregating 7,000 kw., furnished with steam by a battery of forty boilers with a total capacity of 13,500 h. p.

The party, in passing through the works, observed the following operations: Winding of smaller coils by girls; winding of heavier coils by men; electric welding of copper conductors; dipping and drying insulation on high and low-tension transformer coils; making and repairing of moulds for winding coils; punching of insulation into shape; assembling of armature coils; insulating with mica, asbestos and water glass to make field coils fire-proof. In the turbo-generator department: Winding A. C. and D. C. generators, rotary converters and three-wire D. C. generators; electric welding of broken or incomplete castings by the Bemarda system, using 70 volts and 200 to 500 amperes alternating current; fitting and assembling large machines, up to 20,000 kw. generators and to 10,000 h. p. motors; machining the largest armatures, field pieces and bed-plates; assembling the machines for tests; final testing; dissembling for shipment. Special attractions were the winding of large induction motors for main roll driving in steel mills; building and assembling of the 2-000 h. p. motors for the Pennsylvania Railroad electric locomotives,

each 65 feet (20 meters) long, with 68 inches (1.8 meter) drivers, and build to run 70 miles (120 km.) per hour.

The party then proceeded under a viaduct to the works of the

WESTINGHOUSE MACHINE COMPANY, EAST PITTSBURGH, PA.

The Westinghouse Machine Company was organized in 1881, with a working force of 10 men. The works at East Pittsburgh were established in 1896, and now employs over 3,500 men and utilizes over 50 acres of ground. The company manufactures and installs steam engines, steam turbines, condensers, horizontal and vertical gas engines and gas producers.

Steam Engines: Single-acting type, simple and compound, double and single cylinder designs, with piston valves, used chiefly for exciter sets, small power engines and stoker drive.

Steam Turbines: Principally the reaction type. Entirely Parsons reaction type ranging from 300 to 3,000 kw.; double-flow turbines for high-pressure steam with impulse first stage 2,000 to 15,000 kw. capacity. Low-pressure turbines mainly double-flow, 300 to 5,000 kw. Small power turbines for condenser auxiliary drive, exciters, boiler feed pumps, train lighting, etc.; impulse wheels 10 to 200 kw.; train lighting sets, ¾ kw.

Horizontal Gas Engines: Four-stroke, double-acting, constant mixture control, electric ignition system with magnetic tripping device. Either single crank or twin units, ranging from 300 to 4,000 h. p. For blast furnace, natural, coke-oven and producer gas and oil distillate.

Vertical Gas Engines: Single-acting, four-stroke design; two and three cylinder construction; 10 to 300 h. p.; constant mixture control. For producer, natural, coke-oven and illuminating gases, oil distillate and gasoline.

Gas Producers: Suction type, water-sealed ash pits. For anthracite and bituminous fuels. Bituminous producer of the double-zone type.

Leblanc Condensers: Jet type, with special rotating air pump, effecting removal of air by projecting series of sheets of water in a diffuser; these sheets of water entrap the air and force it out of the condenser against atmospheric pressure. No reciprocating parts or wearing surfaces; 10 to 5,000 h. p. capacity.

Test of a Special Condenser for Vacuum Pan Service: In addition to the extraordinary vacuum maintained by the Westinghouse-Leblanc condenser, this apparatus which was on test was capable of producing two different vacuum pressures at the same time. Thus, while the condenser proper is maintaining 28 inches (710 mm.) of vacuum in the last effect, an air line from an intermediate effect is connected in to a special nozzle just below the air pump, which maintains a secondary vacuum of from 10 to 20 inches (250 to 500 mm.), at the same time removing a large percentage of the air entrained in the liquor, and greatly relieving the remainder of the system.

Melville-Macalpine Reduction Gear: With floating frame for equalization of two pressures. Reductions up to a ratio of 12 to 1 and capacity as high as 25,000 h. p. Interlinks turbine of most efficient speed, with propeller of most efficient speed for marine work. Also especially applicable to direct current work in connecting turbine which is of inherently high speed with a generator that must be operated at low speed. Best efficiency and operating conditions thus attained. The party went through the large machine shop, where various machining operations are performed on the different products, such as large engine bed-plates, condensers, engine shafts. At the end of the shop is located the building devoted to the erection of automobile engines. At the north aisle was seen the oxy-acetylene welding process; also bituminous gas producers being assembled and shipped; horizontal gas engines in the course of erection; gas engine governor test; vertical gas engines in course of erection.

Testing gas engines up to 300 h. p. at full load obtained by means of prony brake. Gas consumption measured by means of direct-reading gas meters made by Pittsburgh Meter Company, whose plant is adjacent.

The Leblanc condensers being erected and under test were shown.

Junior and Standard compound single-acting vertical steam engines, the original product of the company at its inception in 1881.

Testing these engines by prony brake; steam consumption measured by condensed steam, using surface condenser.

Assembling and blading steam turbine rotors. Stands for balancing sections of rotors.

The recently-developed Melville-Macalpine-Westinghouse turbine reduction gear. The original experimental set was seen in operation. The set consists of a driving turbine of Parsons type, a reduction gear, and an absorption dynamometer. The speed of the turbine is 1,500 r. p. m., reduced to 300 r. p. m. at the dynamometer shaft by the reducing gear. This set has been thoroughly tested under all conditions of load; the most important test covered a period of 40 hours' consecutive operation, during which the load was kept constant at about 6,100 h. p. It is believed that this absorption dynamometer is the largest ever built.

The Leblanc dry air pump, steam turbine driven, attached to surface condenser in the steam turbine testing department, in close proximity to dry air pump of ordinary horizontal reciprocating type of same capacity, was shown.

FIRTH-STIRLING STEEL COMPANY, DEMMLER, PA.

Only fine crucible steel, for tool purposes, is made at the McKeesport plant. They have installed a large number of crucible furnaces, one 2½-ton Heroult furnace, and one electric resistance furnace. The remaining equipment is the same as found in any crucible steel works, and consists of a number of steam-driven rolls, steam hammers, and electric-driven shears, etc. Power for the motors is obtained from one 250 kw. and

one 150 kw. D. C. generator, belted to steam engine units. The boiler-house contains a bank of six boilers, aggregating some 1,800 h. p.

Of special interest is the 2½-ton Heroult electric arc furnace. The arc is formed between the electrodes and bath of metal and the current, which passes through one carbon, passes through the bath, and out through the other carbon. The carbons project down vertically through water-cooled jackets located on the top of the furnace. The furnace is lined with calcined magnesite or dolomite. The Heroult furnace is nothing more than a modified open hearth, wherein the heat is applied above the metal by the electric current in place of gas. In order to maintain constant load, a regulating device is used. This device electrically operates two motors located on the furnace, whereby the carbons are raised or lowered. The control is made by Ateliers H. Cuenod, Geneva, Switzerland.

Power for the furnace is obtained from the three-phase mains of the Allegheny County Light Co. and stepped down from 11,000 to 110 volts through two 200 kw. single-phase, 60-cycle, Westinghouse "OISC" transformers. These transformers are connected in parallel on the low tension side.

The arc furnace is charged either cold or with metal from an open-hearth furnace. Three heats can be refined, working from cold scrap for 24 hours and probably about 15 heats when working with hot material from the open-hearth furnace. The arc furnace requires about 250 kw., and the resistance furnace about 120 kw.

A similar resistance arc furnace for producing ferro-tungsten alloys for use in special steel was also in operation.

CARNEGIE STEEL CO.: HOMESTEAD WORKS.

A fine group photograph* was taken before inspecting the works, and then various parts of the works were visited, including the Bessemer and open-hearth departments, and the rolling mills.

The special train arrived in Pittsburgh at 5.30 P. M. In the evening an informal dinner was very much enjoyed after the strenuous activities of the day. Over 200 members and guests dined together in the English Room of the Fort Pitt Hotel.* Addresses and interesting remarks were made by L. H. Baekeland, W. H. Walker, Jos. W. Richards and a number of guests and members of the Society.

Section "Q" was strongly in evidence, enjoying itself with its usual *abandon.*

* Copies of the fine photographs taken at the works, and at the dinner, may be obtained from the R. W. Johnston Studios, 241 Fifth Ave., Pittsburgh., Pa., for $2.00 each, or $3.00 for the two.

PROCEEDINGS OF SATURDAY, MAY 7th.

The morning session was called to order at 9.30 A. M. in the lecture room of the Engineering Building of the University of Pittsburgh, President L. H. Baekeland in the Chair.

Dr. D. J. McCormick, Chancellor of the University, welcomed the Society as follows: "I wish to say that you are a thousand times welcome to our University. We wish we were two years older in the new location, in order that we might show you more of our plant. It is now only two years since we began building on this spot and a definite plan was adopted for our expansion. We do not know how Providence preserved this bit of farm land, almost in the heart of the city, for 150 years. Five years ago only a few houses were standing upon it, and now in this immediate locality are the University Club, Soldiers' Memorial, Athletic Club, Armory Building, etc., and soon this hill will be covered with the magnificent buildings which are planned for our University. Our institution is 123 years old, and, after many wanderings, we have at last come to this permanent home, where we will build up a great University.

Although I was brought up in a classical college, where science was practically unknown, yet I may very earnestly and sincerely express my appreciation of the work of such men as you. I want to say that your work, the work of men who seek by experiment and research to understand her forces, is bringing men to kingship over nature. The ancient Greek probably had as fine a brain as we, perhaps even more perfectly organized, and yet, up until the recent past, no one did anything to conquer the forces of nature. There was left to us this great work of investigating and subjugating nature's forces to our purposes. The minister of the Gospel works on the human soul, and I place his work as the highest; but next to him stands the scientist, who works on the natural agencies to make them serve mankind. It is a wonderful thing to harness these and make them our servants, not simply for the purpose of acquiring wealth or comfort, but for the sake of accomplishing and pushing forward the march of civilization.

We are planning large things in this center of University activity, and are in full accord with you in helping on this great work."

At the conclusion of these remarks, papers by D. L. Ordway, H. M. Goodwin (read by W. H. Walker), E. F. Chance, M. deK.

Thompson, H. E. Patten and W. J. McCaughey, R. E. O. Davis, Jas. Breckenridge, J. W. Turrentine, F. C. Frary and A. B. Petersson, W. J. McCaughey and H. E. Patten, F. C. Mathers, S. E. Whiting, H. K. Richardson, and R. L. Patterson were presented, read and discussed, as printed in full in the Transactions.

Prof. J. W. Richards moved, and Mr. Carl Hering seconded, the following resolution:

"The American Electrochemical Society places upon record its most cordial and appreciative thanks to all those persons and firms of the Pittsburgh district who have so splendidly contributed to the success of the Seventeenth General Meeting of the Society, in the city of Pittsburgh.

"It records its high appreciation of the kindness and courtesy of:

"The officials and technical staff of the United States Geological Survey Testing Station, for their interesting and highly instructive demonstrations.

"The officials and working staff of the Carnegie Steel Co., at their Isabella Furnaces, the Park Works of the Crucible Steel Co. of America, The Jones & Laughlin Steel Co., The Pennsylvania Smelting Co., The Universal Portland Cement Co., The Pittsburgh Reinforced Brazing and Machine Co., The Nernst Lamp Co., The Allegheny Plate Glass Co., The Westinghouse Electric and Manufacturing Co., The Firth-Stirling Steel Co., and the Carnegie Steel Co., at the Homestead Works, for the highly enjoyed visits permitted to their respective plants, and the courtesy and attention with which the visitors were received.

"To the trustees and faculty of the University of Pittsburgh, for a meeting place and most hearty reception, the Society expresses its sincere thanks.

"To the Engineers' Society of Western Pennsylvania, and to the German Club, the Society is indebted for most kindly extended social privileges.

"To the Carnegie Technical Schools, and Carnegie Institute and Museum, for kind invitation to visit their buildings and inspect their collections.

"To the management of the Fort Pitt Hotel, for use of its Assembly Rooms and numerous facilities most willingly furnished.

"To the Bell Telephone Co. of Pittsburgh for special telephone facilities at the Registration Bureau.

"To the local press, for its full and accurate accounts of the meeting.

"And, finally, to the Ladies Committee, for their assiduous attention to the comfort and pleasure of the visiting ladies, to the efficient Chairmen of the sub-committees on Press, Excursions, Meetings and Hotels, and their assistants, and to all the members of the Local Committee who so freely sacrificed time and energy for the comfort, pleasure and edification of the members of the Society."

The resolution was carried by acclamation.

At noon the members and guests partook of lunch at the Hotel Schenley.

In the afternoon, at 2.30 P. M., a General Public Meeting was held in the Carnegie Music Hall.

Dr. Jos. W. Richards, Secretary, delivered an illustrated address on "What the Electrochemical Industries Are Accomplishing."

Mr. John H. Finney, Secretary of the Southern Appalachian Conservation Commission, on "The Conservation and Utilization of Natural Sources of Power."

Dr. John A. Brashear, "Pittsburgh's first citizen," addressed the Society in a reminiscent vein upon the past and present advantages of Pittsburgh.

The audience at this meeting was representative of the various interests of Pittsburgh, and listened with great attention and evident appreciation of the proceedings.

After the adjourning of this meeting, the visitors spent the rest of the afternoon inspecting the Carnegie Museum, Technical Schools and the University of Pittsburgh.

In the evening, members and guests remaining in the city were invited to make themselves at home at the German Club, and to participate in a *Conversazione* at the new headquarters of the Engineers' Club of Pittsburgh.

Entertainment of Ladies.

An active Ladies' Committee arranged a most enjoyable entertainment for the visiting ladies, who were 21 in number.

On Wednesday afternoon the ladies participated in the visit to the United States Geological Testing Plant, and in the reception at the Fort Pitt Hotel.

On Thursday afternoon they were conducted through the Heinz factory, the home of the famous "57."

On Thursday evening the ladies participated in a theater party.

On Friday an extensive automobile trip around Pittsburgh and through its parks was greatly enjoyed.

On Friday evening the ladies participated in the dinner at the Fort Pitt Hotel.

On Saturday morning an excursion was arranged for the ladies at the various art galleries, museums and schools in the vicinity of Schenley Park. On Saturday afternoon they attended the general public meeting.

It may not be out of place to remark that the local weather bureau furnished four cloudless days of most magnificent weather, which increased in a high degree the enjoyment of our stay in Pittsburgh.

ANNUAL REPORT OF THE BOARD OF DIRECTORS.

To the Members of the American Electrochemical Society:

We submit herewith the annual report of the Secretary and the Treasurer for the year of 1909, the former containing the detailed financial statement of receipts and expenditures.

The increase of the number of members was highly satisfactory, being over 37%, as against 13% in 1908. A considerable expenditure for the purposes of the Membership Committee, authorized by the Board of Directors during 1908 and 1909, proved a profitable investment for the Society. The membership at date of this meeting is, in round numbers, 1,133, with 35 members elected but not qualified by payment of dues, and a list of 30 applicants to be elected at the end of this month, so that the number of members to date is practically 1,200.

The financial status of the Society during 1909 was highly satisfactory. The excess of receipts above expenditures for the year was over $1,400, from which the permanent investment fund has been increased by the purchase of another $1,000 5% inter-

est bearing bond. The equity of the Society in the three $1,000 bonds which it now holds, diminished by the $500 Ferro-boron prize held in trust, is over $2,500.

The following are the more important actions taken by the Board of Directors during the past year:

The Secretary was directed to double the selling price of any volume of Transactions, whether sold singly or in sets, when the number of that volume reaches 200. (Volume III now comes under this rule.)

At the request of the Sixteenth General Meeting, the Board of Directors appointed the following committee to investigate and report upon the "Testing and Rating of Dry Batteries": Prof. C. F. Burgess, Chairman; Dr. C. H. Sharp, Dr. J. W. Brown and Mr. F. H. Loveridge.

Authors shall be requested to insert in their papers, after each and every numerical expression in English units, the corresponding equivalent value in metric units, within parentheses, and to a degree of precision conformable with that of the English expression. Such equivalents may be conveniently obtained from the Table of Metric Equivalents published by the Bureau of Standards. In case of a paper being presented with such parenthetical metric equivalents omitted, the equivalents will be inserted in the Secretary's office before the paper is published.

The usefulness and influence of our Society are increasing rapidly, and its national importance and international prestige are such that every member has a right to feel proud of its achievements. Let us fully realize the increasing responsibilities attendant upon such a wide sphere of usefulness, so as not to be found wanting in our further efforts.

L. H. BAEKELAND, *President.*
J. W. RICHARDS, *Secretary.*

Pittsburgh, Pa.,
May 5, 1910.

SECRETARY'S ANNUAL REPORT

To the Board of Directors of the American Electrochemical Society:

GENTLEMEN:—In 1909 the Society held two general meetings, one at Niagara Falls, Canada, May 6th, 7th and 8th, at which the

attendance was 187 members and 136 guests, total 323; and the second in New York City, October 28th, 29th and 30th, at which the attendance was 161 members and 190 guests; total, 351. At the spring meeting 45 papers were read, at the autumn meeting 19 papers were read and 20 published.

In 1909 there was issued and distributed to our members two volumes of our Transactions. Volume XIV was of the New York City meeting of October 30-31, 1908; Volume XV of the Niagara Falls meeting of May 6-8, 1909. These volumes contained 274 and 628 pages, respectively. The Transactions of the New York City meeting of October 28-30, 1909, were issued as Volume XVI on February 19, 1910; it contained 479 pages.

The edition of Volume XIV was 1,000 copies, bound in cloth, for distribution to our members; 50 extra copies, in sheets, for distribution in pamphlet form to authors of papers, and 250 copies, bound in paper, for distribution to members of the Faraday Society, and 250 copies, sewed ready for binding, to be kept in stock.

The edition of Volume XV was 1,250 copies, bound in cloth, and 50 extra copies for authors; 250 copies, bound in paper, for the Faraday Society, and 500 copies, sewed ready for binding, which are kept in stock. In the 16 volumes now issued as the Transactions of the first eight years' activity of the Society, there are contained 403 communications, covering 5,700 pages.

Complete sets of all these volumes are still on hand, but the stock is diminishing, and Volume III, which is nearly exhausted, is sold, according to the action of the Board of Directors, at double price.

There were on hand December 31, 1909:

Volume	Bound in Cloth	Bound in Paper	Total
I	352	9	361
II	281	0	281
III	182	0	182
IV	204	235	439
V	154	235	389
VI	171	242	413
VII	173	248	421

	Bound in Cloth	Bound in Paper	Total
VIII	186	238	424
IX	189	275	464
X	201	258	459
XI	165	262	427
XII	209	266	475
XIII	124	218	342
XIV	340	275	615
XV	133	525	658
Total			6,350

Condition of the Society in regard to membership:

Members January 1, 1909		776
Elected and qualified as members in 1909		343
		1,119
Resigned in 1909	19	
Deaths	9	
Dropped for non-payment of dues	25	
		53
Members December 31, 1909		1,066
Net gain in membership in 1909		290

Financial Statement.

January 1, 1909, to December 31, 1909.

RECEIPTS.

Entrance fees	$ 1,715 00
Dues	5,853 57
Sales of publications	1,216 50
Membership certificates	86 00
Interest on investments and bond account	166 22
Sale of investment. (Lower Merion 3½% bond)	975 00
Advertising in Transactions (net proceeds)	206 44
Donation, Niagara members (surplus, 15th meeting)	7 07
Temporary loan	500 00
	$10,725 80

EXPENDITURES.

Publications	$ 3,694 09
Membership certificates	20 70
Miscellaneous printing	452 50
Postage	746 50
Office expenses	388 88
Salary, Secretary and Assistants	871 92
Meetings	412 77
New York Section appropriation	144 80
Membership Committee	861 41
Faraday Transactions (extra copies)	105 90
Storage on Transactions	38 50
Insurance	10 44
Repayment of temporary loan	500 00
Permanent investments	2,080 42
	$10,328 83

ASSETS, JANUARY 1, 1909.

Cash balance, January 1, 1909—On deposit		$ 443 62
Cash box		50 00
Bonds held by the Society (cost price)	$1,948 75	
Ferro-Boron prize, held in trust	500 00	
Equity of Society in above bonds		1,448 75
		$1,942 37

ASSETS, DECEMBER 31, 1909.

Cash balance, December 31, 1909—On deposit		$ 840 59
Cash box		50 00
Bonds held by the Society (cost price)	$2,998 75	
Ferro-Boron prize, held in trust	500 00	
Equity in above bonds		2,498 75
		$3,389 34
Gain in assets for the year of 1909		$1,446 97

The Society is prospering financially, scientifically and socially. It is furnishing its members with a large and abundant service at a very small yearly investment.

The possibility of an excess of expenses above receipts seems

157547

to have permanently passed away, and the continued progress of the Society in numbers and usefulness to its members is assured.

JOSEPH W. RICHARDS,
Secretary.

Lehigh University, South Bethlehem, Pa.,
May 1, 1910.

TREASURER'S ANNUAL REPORT

FOR THE YEAR 1909.

Balance, January 1, 1909		$ 493 62
Receipts from Jos. W. Richards, January 1, 1909, to December 31, 1909	10,725 80	
		$11,219 42
Payments, January 1 to December 31, 1909, as per list	10,328 83	
Balance, December 31, 1909		$ 890 59

PEDRO G. SALOM,
Treasurer.

We the undersigned have examined and compared the receipts and expenditures of the American Electrochemical Society, and find the same to be correct.

(Signed) HENRY G. MORRIS,
S. S. SADTLER,
Auditors.

MEMBERS AND GUESTS REGISTERED AT THE SEVENTEENTH GENERAL MEETING.

Members.

G. P. Adamson
R. Amberg
Jas. C. Armor
W. C. Arsem
Jas. Aston
J. E. Babb
A. Bachert
L. H. Baekeland
Jas. M. Barrett
John W. Beckman
P. McN. Bennie
Percy A. Boeck
Gideon Boericke
Hugo DuBois
Wm. Brady
Wm. H. Bristol
W. B. Brookfield
J. T. Brown
J. W. Brown
Chas. L. Bryden
N. W. Buch
C. F. Burgess
J. R. Cain
H. R. Carveth
Chas. R. Cary
H. Casselberry
Adolphe Chalas
D. H. Childs
G. B. Chorpening
C. C. Cito
E. B. Clarke
W. R. Clymer
Wallace P. Cohoe
Ed. A. Colby
H. R. Connell
Sidney Cornell
Fred. Crabtree
J. S. Crider
Chas. W. Danforth
Stewart A. Davis
Colby Dill
H. E. Diller
W. A. Donkin
Chas. A. Doremus
John W. Dougherty
L. H. Duschak
Saul Dushman
J. J. Eckfeldt
Dexter Edge
C. G. Fink
H. W. Fisher
J. J. Flannery
Chas. E. Foster
M. W. Franklin
E. Friedlaender
H. Frodshain
H. A. Gardner
Arthur E. Gibbs
W. T. Gibbs
H. W. Gillett
J. S. Goldbaum
S. L. Goodale
G. M. Goodspeed
J. H. Goodwin
J. M. Graves
W. G. Graves
A. E. Greene
C. A. Hansen
R. H. Hartley
E. Hensen
C. Hering
P. L. Heroult
B. F. Hessom, Jr.
H. D. Hibbard
E. F. Hicks
H. K. Hitchcock
A. H. Hooker
H. Howard
L. E. Howard
E. J. Hutchinson
A. S. Isaacs
A. von Isakovics
K. Iwai
J. H. James
Reese James
C. F. Jenkins
H. W. Kellogg
P. Kemery
E. F. Kenney
S. M. Kier
F. L. Koethen
M. M. Kohn
A. B. Lamb
H. M. Lane
J. Langton
H. H. Laughlin
E. J. Lavino
J. D. Lewis
F. A. Lidbury
P. M. Lincoln
M. G. Lloyd
F. H. Loveridge
C. W. Lytle
C. W. Marsh
E. J. K. Mason
W. McGregor
Jos. McKinley
J. E. McKirdy
J. L. Merrill
H. S. Miner
C. H. Moritz
W. R. Mott
H. N. Mueller
D. H. Murphy
J. E. Ober
D. L. Ordway
L. A. Osborne
G. S. Page
C. W. Parkhurst
L. A. Parsons
John C. Pennie
R. S. Perry
N. Petinot
A. Pinkerton
A. L. J. Queneau
R. C. Reed

Members (Continued).

P. P. Reese
Jos. W. Richards
H. K. Richardson
C. D. Robb
A. G. Rodgers
H. Rodman
E. F. Roeber
F. W. Roller
T. Rowland
Louis Ruhl
B. Rutherford
S. S. Sadtler
B. D. Saklatwalla
L. E. Saunders
W. M. Saunders
C. G. Schluederberg
A. P. Scott
Chas. F. Scott
R. L. Seabury
R. W. Seabury
J. A. Seede
H. F. Sill
V. Skillman
C. E. Skinner
F. L. Slocum
A. W. Smith
E. S. Smith
Wm. A. Smith
E. H. Smythe
W. O. Snelling
J. L. K. Snyder
A. L. Sonnhalter
W. L. Spalding
E. C. Speiden
F. N. Speller
E. A. Sperry
E. C. Sprague
S. G. Stafford
R. H. Stevens
F. M. Sturgess
Chas. E. Taylor
E. R. Taylor
B. F. Thomas
R. D. Thomas
S. A. Tucker
F. Uhlenhaut, Jr.
J. S. Unger
C. C. Vogt
L. D. Vorce
M. Waddell
F. L. O. Wadsworth
S. S. Wales
W. H. Walker
H. E. Walters
G. S. Warren
O. P. Watts
W. S. Weedon
G. Werliin
R. H. White
J. Whiting
C. S. Wickes
B. Wiley
T. A. Witherspoon
J. R. Withrow
W. J. Wooldridge
J. A. Yunck

Guests.

Mrs. W. C. Arsem
Mrs. L. H. Baekeland
Mrs. B. E. Broadwell
Mrs. C. L. Bryden
Mrs. E. B. Clarke
Mrs. W. R. Clymer
Mrs. J. S. Coye
Mrs. F. Crabtree
Mrs. H. W. Fisher
Mrs. Gass
Mrs. W. T. Gibbs
Miss Gibbs
Mrs. S. L. Goodale
Mrs. R. H. Hartley
Mrs. E. P. Hitchcock
Mrs. A. von Isakovics
Mrs. C. F. Jenkins
Mrs. P. Kemery
Mrs. H. C. Laudebeck
Mrs. H. H. Laughlin
Mrs. P. M. Lincoln
Mrs. B. E. V. Luty
Mrs. R. J. Mitchell
Mrs. H. N. Mueller
Mrs. J. E. Ober
Mrs. Chas. F. Scott
Mrs. F. N. Speller
Mrs. S. G. Stafford
Mrs. E. R. Taylor
Miss E. B. Taylor
Mrs. S. S. Wales
Mrs. J. Whiting
Mrs. J. A. Yunck

H. F. Affelder
A. G. Ahrens
I. C. Allen
R. Anderson
W. C. Andrews
R. B. Anthony
R. W. Atkinson
G. H. Aupperle
J. A. Aupperle

Guests (Continued).

H. Bacharach
Chas. Bailey
H. Barbour
W. E. Barnes
A. M. Barron
G. C. Bauer
J. Bechtel
A. W. Belden
H. Beltz
G. H. Blaxter
A. D. Bleinenger
E. Blough
J. J. Boyle
J. D. Breneman
B. E. Broadwell
G. H. Brown
R. C. Brown
R. V. Buigay
H. R. Bulmer
W. R. Burrows
A. R. Calder
J. D. Callery
C. B. Callomon
G. D. Chamberlin
W. P. Champney, Jr.
R. B. Chillas, Jr.
E. C. Chrisown
J. K. Clement
W. C. Coffin
F. Collins
Wm. F. Collman
A. L. Colton
J. S. Coye
H. H. Craver
F. S. Crawford
F. B. Crosby
W. B. Crowe
A. W. Crownover
G. H. Danforth
H. E. Davis
W. B. Davis
A. H. Dean
B. Dewey
F. H. Dimock
H. Dripps
S. N. Dunbar
H. R. Edgecomb
H. F. Engelbrecht
H. W. Erhing
G. Fesserkes
H. A. Field
A. C. Fieldner
C. G. Fisher
G. H. Follows
J. L. Foster
J. W. C. Fraser
H. L. Fullerton
Andre Gerard
J. A. Gerhart.
C. L. Gerwig
W. H. Gibb
S. P. Grace
C. M. Graves
J. H. Grove
R. S. Guerber
H. R. Hadfield
J. Hall
J. O. Handy
N. Hecht
C. T. Henderson
H. W. Heinz
P. H. Heroult, Jr.
H. O. Hill
C. R. Hodgdon
M. Hokanson
S. P. Howell
W. P. Hurley
R. H. Hursh
W. G. Ireland
H. Isenberg
W. P. Jend
F. R. Jennings
H. R. Jessy
E. B. Jewett
R. W. Johnson
J. S. Johnston
J. L. Jones
W. P. Jones
O. M. Jorstad
E. F. Joyce
J. A. Kelley
F. B. Kelly
C. L. Kemery
A. Kingsbury
F. Kjeim
L. L. Knox
C. R. Krueger
Dr. R. Krulla
E. F. Lake
H. G. Lamker
H. C. Laudebeck
G. H. Leeds
R. B. Leighton
W. B. Lindall
D. H. Littell
C. Longanecker
A. Lowenstein
B. E. V. Luty
J. K. Lyons
W. L. Macloskey
G. E. Marble
S. J. Marchan
J. F. Martin
H. V. Mason
J. E. Maten
F. L. May
W. A. McCaffey
E. H. McClelland
W. M. McConahey
W. H. McCune
R. A. McDonald
J. H. McFeely
J. N. McIlvaine
F. F. McIntosh
T. McIntosh
W. N. McKee
W. N. McKnight
D. J. McLaughlin
C. A. Menks
E. S. Merriman
L. A. Meyran
H. S. Miller
G. B. Mitchell
L. A. Moran
W. P. Morgan

Guests (Continued).

R. Morris
E. K. Morse
J. M. Muir
S. Myasaki
H. A. Neel
Geo. Neilson
A. B. Norton, Jr.
J. A. O'Callaghan
L. R. Palmer
F. L. Parker
A. C. Parsons
W. C. Parsons
F. B. Porch
H. C. Porter
K. C. Randall
H. S. Randolph
J. C. Reed
W. E. Reed
C. R. Reicher
C. R. Rhodes
C. H. Rich
H. K. Rigdon
J. C. Roberts
F. Rose
W. J. Rouch
H. H. Rudd
D. J. Russin
C. F. W. Rys
A. C. J. Schabacker
J. A. Schaeffer
C. H. Schultz
R. C. Schwarz
H. W. Seldon
F. M. Sickler
A. Silvermann
A. T. Simonds
R. H. Skinner
H. Slocum
M. A. Smith
R. G. Smith
J. A. Smitsmans
R. A. L. Snyder
A. W. Soderberg
E. R. Spencer
H. H. Stevens
C. G. Storm
W. J. Strassbergh
H. Styn
M. Tattersfield
H. G. Texter
E. C. Troutman
C. P. Turner
M. C. Turpin
F. Uhlenhaut
G. N. Vardy
R. M. VonHofen
A. A. Wagner
W. H. Wagner
W. E. Waggoner
W. G. Waitt
J. A. Ward
M. M. Waterman
R. H. Watson
G. E. Webster
G. A. White
W. Whited
M. A. Whiting
R. S. Wile
W. B. Wilkinson
J. E. William
W. A. Williams
T. A. Worcester
Wm. R. Work
E. Yawger
Wm. Yost
R. L. Young

Members Elected and Qualified.

November, 1909—May, 1910.

November 27, 1909.

Wm. N. Burson, Rockford, Ill.
F. V. Greene, Buffalo, N. Y.
Wm. B. Bragdon, Westbrook, Cumberland Mills, Me.
August E. Bachert, Tyrone, Pa.
Jas. Douglas, New York City.
C. M. Seidel, Havana, Cuba.
Merle Randall, Boston, Mass.
C. H. Lihme, La Salle, Ill.
Chas. B. Thwing, Philadelphia, Pa.
Colby Dill, Perth Amboy, N. J.
E. A. Mays, New York City.
N. S. Hill, Jr., New York City.
G. Monrath, New York City.
M. H. Johnson, Utica, N. Y.
W. F. Bleecker, Boulder, Col.
O. A. Kenyon, New York City.
Wm. A. Converse, Chicago, Ill.
Paul O. Abbe, New York City.
J. H. Brickenestein, Washington, D. C.
Chas. L. Bryden, Scranton, Pa.
E. F. Eurich, New York City.

Members Elected and Qualified (Continued).

J. M. Walton, Brooklyn, N. Y.
J. S. Goldbaum, Philadelphia, Pa.
B. L. Murray, Rahway, N. J.
L. O. Hart, Harrison, N. J.
E A. Widmann, New York City.
R. W. Seabury, Boonton, N. J.
Chas. D. Robb, New York City.
Chas. A. Weeks, Philadelphia, Pa.
J A. Flanigan, Paterson, N. J.
F. M. Hess, Bishop, Cal.
Wm. V. Geib, Baltimore, Md.
F. H. Millener, Omaha, Neb.
Wm. C. Arsem, Schenectady, N. Y.
F. McM. Stanton, New York City.
W. V. Young, Chicago, Ill.
W. W. Case, Denver, Col.
J. F. Clapp, Los Angeles, Cal.
H. H. Hillegass, State College, Pa.
M. Unger, Pittsfield, Mass.

December 31, 1909.

A. H. Eustis, Boston, Mass.
W. L. Badger, Brush, Col.
W. S. Barwick, Vancouver, B. C.
Chas. E. Skinner, Wilkinsburg, Pa.
G. M. Colvocoresses, Gowganda, Ont.
L. E. Imlay, Niagara Falls, N. Y.
H. Binney, New York City.
E. DeSouza, S. Paulo, Brazil.
C. H. Bowman, Butte, Mont.
J. Newbery, Buenos Aires, A. R., South America.
F. H. Loveridge, Chicago, Ill.
T. K. Arunachela, Bangalore, S. India.
F. D .Taylor, State College, Pa.
H. F. Sill, Pittsburgh, Pa.
B. Stoughton, New York City.
Wm. J. Cummings, Haskell, N. J.

January 29, 1910.

F. C. Bowman, Denver, Colo.
Chas. E. Lord, Milwaukee, Wis.
J. R. Taylor, New York City.
F. L. Koethen, Pittsburgh, Pa.
D. J. McAdam, South Bethlehem, Pa.
K. Nishikawa, Kyoto, Japan.
R D. MacLaurin, Toronto, Canada.
F. N. Speller, Pittsburgh, Pa.
A. O. Tate, Toronto, Canada.
R. F. Hayward, Vancouver, B. C.
E. E. Carey, San Jose, Cal.
W. MacGregor, Indiana Harbor, Ind.
Thos. P. Gill, Villa Nove de Lima, Minas Geraes, Brazil.
L. M. Rossi, Perth Amboy, N. J.
T S. V. De Medeiros, Rio de Janeiro, Brazil.

February 26, 1910.

E. F. Kenney, Johnstown, Pa.
Lee Fraser, San Mateo, C. R., Central America.
W. L. Morrison, Webster, N. C.
A. J. Boynton, Lorain, O.
B. F. Bennett, Madison, Wis.
T. C. Martin, New York City.
J. E. Babb, Pittsburgh, Pa.
A. S. Dwight, New York City.

March 26, 1910.

V Skillman, Ithaca, N. Y.
H. W. Gillett, Ithaca, N. Y.
W. F. B. Leavitt, New York City.
G. C. Furness, Niagara Falls, N. Y.
H. L. Hancock, Moonta Mines, South Australia.
D. K. Bachofner, Irvington, N. J.
W. J. Crowell, Jr., Lebanon, Pa.
C. C. Vogt, Pittsburgh, Pa.
H. E. Diller, Schenectady, N. Y.
R. Amberg, Chicago, Ill.
G. W. Hayes, New York City.

Members Elected and Qualified (Continued).

May 5, 1910.

D. L. Ordway, Cleveland, O.
Ralph C. Schwarz, Rochester, N. Y.
C. H. Halcomb, Cazenovia, N. Y.
D. H. Murphy, Pittsburgh, Pa.
J. L. K. Snyder, Cleveland, O.
F. L. White, Cleveland, O.
W. W. Mann, Cleveland, O.
R. B. Chillas, Cleveland, O.
E. J. Humel, Cleveland, O.
W. P. Samuels, Sharon, Pa.
E. C. Peck, Cleveland, O.
W. M. Corse, Buffalo, N. Y.
W. A. Cowan, Brooklyn, N. Y.
E. B. Cook, Pottstown, Pa.
J. W. Hornsey, New York City.
W. B. Pritz, Cleveland, O.

The Presidential Address, delivered at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 5, 1910, Vice-President C. A. Doremus in the Chair.

SCIENCE AND INDUSTRY.

By Dr. Leo. Hendrik Baekeland.

The present age surpasses all previous epochs of history by the intense activity of the human race, the daring of its efforts, the magnitude of its accomplishments.

We know of periods in history where great wars, great political developments, migration, religious fervor, newly- discovered lands, or other causes, brought forth considerable changes in some nations, but never was the movement so widespread in geographical location, never were impulses operating so rapidly, nor on so extensive a scale as today.

We have not reached the end of this movement; quite on the contrary, it seems to gain in intensity as the years roll by.

While some few nations have taken the lead in certain lines of human endeavor, we know, on the other hand, that the same influences are at work, even in the most remote corners of the world. Countries which for ages have been dreaming dreams of rest, countries of which the political, intellectual, social or industrial conditions have remained practically unchanged for hundreds, nay, thousands of years, begin to awaken; willingly or unwillingly they, too, seem to undergo, albeit in a smaller degree, this all-pervading tendency of enterprise, this aggressive effort to better utilize their opportunities for material, social and intellectual betterment.

In other words, modern human dynamics have reached an intensity never witnessed before.

It looks to me as if all great feats recorded in the history of our race sink to nothingness if compared to what human activity is accomplishing every day since ignorant, arrogant, emotional, spasmodic efforts are slowly but surely giving place to methodical and persistent work based on exact scientific knowledge.

Whether the human race has been made happier by all this, I

shall not here try to decide. Happiness is a very subjective condition of mind, very difficult, if not impossible, to measure or to compare; the happiness of the child or the savage, and the happiness of the intellectually developed adult are two entirely different propositions. I believe, however, that even case-hardened pessimists ought to admit that our *opportunities for happiness* have considerably increased, even if so many people, not knowing better, continue to trample upon these very opportunities, blinded as they are by false ideals or by misguided aspirations.

True, the pessimist may point to the slums of large cities, to poverty, to vice, to unsatisfactory labor conditions, to high cost of living. But, what is all that compared to conditions in bygone ages? Where are the famines, the plagues, which not so long ago periodically devastated Europe, and which are still the scourge of some backward countries, like India, China and Russia?

Political corruption, dishonesty and greed are still too much in evidence, and there is still much room for higher ethics; on the other hand, anybody who wants to give himself the trouble to investigate real history will have to admit that the morals and conduct of life of many of the most exalted personages of the past, would fall way below the test of the plain average decent citizen of our republic to-day.

Most certainly there is still abundant necessity for improvement, and our race will improve as long as we put more pride in raising better children than in finding an excuse for our littleness or a consolation for our failures, by bragging about the supposed importance of our ancestors.

Nowhere have the changes of this century been so accentuated as in our industrial enterprises. We know, furthermore, that just such industries, where the developments have been most staggering, are exactly those which have utilized scientific knowledge to the largest extent. Wherever the engineer has been able to put into practice the secrets which the scientist has wrung from nature's laws, there also do we see results so far in advance, as compared to what formerly existed, that only a man with a dead soul fails to be stirred up to admiration and enthusiasm.

The modern engineer, in intellectual partnership with the scientist, is asserting the possibilities of our race to a degree never

dreamt of before; instead of cowing in wonder or fear like a savage before the forces of nature, instead of finding in these forces an object of superstition or terror, instead of perceiving in them merely an inspiration for literary or artistic effort, he learns the language of nature, listens to her laws, and then, strengthened by her revelations, he fulfils the mission of the elect and sets himself to the task of applying his knowledge for the benefit of the whole race.

Let me assert it emphatically: The two most powerful men of our generation are the scientist and the engineer.

Society at large is far from realizing this fact, simply for the reason that the scientist and the engineer manifest their power not as despots, nor as cruel tyrants. Their might is not put in evidence by the amount of chattel-slaves they hold in bondage, nor by the barbaric splendor of their lives; it is not marked by the devastation wrought by armies; their work does not consist in conquering and subjugating weaker nations; we do not see them glorified in painting and sculpture; we do not hear their exploits extolled in song and rhyme; no artists have had to record their triumphant homecoming, greeted as saviours and heroes, while marching over the mutilated corpses of their fallen enemies; they do not use their power to sow sorrow, death and misery, or to steal and plunder or fill the museums of a city like Paris with treasures of art taken by force from weaker nations. No, the masses are unaware of the immense power of the scientist and the engineer because both of them modestly play the role of "the servant in the house"; their unassuming life is devoted not to slaughter, destruction or coercion, but to the service of mankind. They do not build useless pyramids cemented with the sweat and blood of overabundant slaves, monuments to vainglorious despots, witnesses to the small value which was put in ancient times on human life and on human labor.

But the modern engineer applying the principles of science raises buildings far superior in size and conception to any architecture bygone ages can boast of; edifices incomparably more comfortable, more hygienic, more appropriate than anything built before. He raises these gigantic structures in as many days as it took years to build a temple.

In fact, after a few years he is ready to pull the same buildings

down, to erect better and bigger ones, in order to suit advanced conditions, and—nobody cares about the name of the architect or the engineer, nor does the builder care himself.

And why should anybody care? The dynamics of the age are producing changes at such a rapid rate that nowadays any building of whatever size it be, is begun with the feeling that before long it will have to come down to give place to new conditions. Erecting a 20-story building in a city like New York is about like putting up a temporary tent, which may suit us for a while, but has to be taken down whenever conditions, in the onward march of civilization, demand it. Palaces and other buildings which would have made the pride of older nations, are torn down now after a career of less than twenty years to make room for the development of our cities, to allow larger and better-adapted edifices to take their place, which probably in a relatively short time will follow their predecessors and be torn down in their turn, when our children begin to realize that they want streets four or five times wider than our now overcrowded thoroughfares.

The modern engineer and the scientist realize that much more enduring monuments than stone, brick, or bronze will mark the work of this period: they know that the diffusion and application of exact knowledge is shaping the destiny of future generations and will afford more lasting evidence of their efforts than temples or statues; they believe that their work will not count merely for material betterment, but that improved material opportunities created by them will bring forth better people, higher ideals, a better society.

To put it tersely, I dare say that the last hundred years, under the influence of the modern engineer and the scientist, have done more for the betterment of the race than all the art, all the civilizing efforts, all the so-called classical literature of past ages, for which some respectable people want us to have such an exaggerated reverence.

Consistent in their mission of true, powerful men and of servants of our race, the engineer and the scientist perform their work steadily but quietly; they are not appreciated by the unthinking multitude because of the fact that their modesty is usually as great as their achievements.

True, I know some of them who do not exactly "hide their light under a bushel"; but show me the most vain engineer or the most conceited scientist, and he will appear like the very picture of meekness and modesty if you will put him alongside some artists, some writers of fiction, some opera singers, or opera composers.

Let me insist on the fact that every one of our betterments in material conditions, every increase in our opportunities in life has been the entering wedge of vastly improved social, political and ethical changes.

The steamships of today, to which the armadas of yore, and the fleets of antiquity look like mere children's toys, bring distant nations, distant men, nearer together; so do the railroad, the press, the telegraph, the telephone.

Not only have time and distance been shortened by the industrial applications of science, but life has been lengthened in years, and still much more in accomplishments and in opportunities.

Improved means of communication do not only facilitate the exchange of products between far away nations, and allow them to compete in quality and price in the most remote corners of the world's market, but they enable more lasting exchanges than merely those of material commodities; we intermingle, develop, and distribute thoughts and knowledge which slowly but surely modify and perfect the political and ethical conditions of nations as well as of individuals.

Not so long ago, opportunities for travel, for education, wealth or comfort of existence, were given only to a very few; now in our modern community all these advantages have come within the reach of the multitude, and all this, thanks to our industrial developments.

Much has been said and written about the civilizing influence of the discovery of the printing press. Has it ever occurred to you that the printing press could accomplish very little if we had not invented the means for manufacturing cheap and good paper? In the same way every facility which science and engineering has endowed the world with finds itself reflected in the ever-increasing development of printed publications. For one book that was written a few centuries ago, thousand better prepared ones are published nowadays. Ancient authors had few

competitors and few readers, and the latter could afford to remember the names of their authors, and greatly exaggerate their merits, and overawe following generations with the extent of their importance, and hypnotize some of us in the belief that there are no good authors but dead authors, or ancient authors, an opinion unfortunately shared by some respectable pedagogues.

Today, when illiteracy is no longer the rule but the exception, new ideas, new conceptions are carried to all points of the globe: measured, discussed, hacked to pieces, or developed, all this with a rapidity never attained heretofore; and I believe that one of the most important causes of our rapid mental and industrial progress is due to the very swiftness with which information and knowledge penetrate the masses.

The man who nowadays would try to stem the tide of ideas, or intellectual advance, would only succeed in making himself ridiculous.

In the middle ages some devout people, not knowing better, could try to burn scientists and their books, and opposed for a while the march of progress, because there were so very few scientists and so few books to burn. But, nowadays, it would require more than all the combined blast furnaces of Pittsburgh to keep up this process of oxidation.

It helps a country like Russia very little to have some highly-developed men, some great scientists, great philosophers, as long as the multitude of the rural population remains in ignorance and lowness; as long as so many people are prevented by unsatisfactory material conditions to profit by the influence of their better fellow-men.

In a self-respecting community the benefits of modern conditions and opportunities for advancement are open for everybody and privileges of birth and class are now considered an anachronism, if not a crime against the human race. Yet few men stop to compare the conditions of modern life with those of the good olden times. An average man, who thinks himself underpaid and imagines he is living at a very modest pace, does not realize that when he is traveling in a modern railroad train, he enjoys comforts and advantages never dreamt of by the richest or most powerful men, princes or kings of scarcely a century ago; he forgets that his life is surer, that his health is better taken care

of than that of any potentate of former times; that the nation respects more permanently his rights as a citizen than was the case of prime ministers of 100 or 200 years ago; that his sons and daughters have better and surer opportunities of education and intellectual advancement than the children of kings of past centuries, that there is no beautiful thought in this world, no knowledge, which is not accessible to him and everybody who can read.

Man only considers a thing a luxury as long as his fellow-men cannot get it, never mind whether it be a bit of glass or a diamond, a bicycle or an automobile; commodities of modern life cease to be considered as luxuries as soon as they become easily accessible to everybody.

Neither should we be too much disappointed in meeting so many people who seem to be oblivious to our improved conditions as compared to those of former times. Society has been pushed ahead, against the will of the masses, by a few active, daring, restless men, who forced the others to follow; just like a herd of unthinking sheep is unwillingly driven forward by the shepherd and his dogs. Many people among whom we live have truly been prodded into progress; they may properly be called remnants of bygone times, symptoms of mental atavism of the race; they do not properly fit in our age; they have passively drifted along on the advancing stream of centuries, to be carried beyond where they properly belong, and now they constitute the ballast which impedes the dynamics of our modern generation.

It has been asserted so often by respectable people that science and industry cater only to our material welfare, and have little in common with culture, refinement or moral development; therefore I feel compelled to put special emphasis on this side of the question and to insist on the enormity of this error; on the contrary, the development of our industries, of our material prosperity, as well as the study and application of science are the surest and most immediate forerunners of higher civic ideals, of an improved society, of a better race.

A clean, well-nourished and well-housed individual, who can enjoy the comforts and advantages of modern surroundings, and leads an active, intelligent, productive, self-supporting and self-respecting life, is certainly more of a man and a credit to his race

than were some ancient saints, who lived from alms and spent their life in prayer and inaction, or who, for further edification of their followers, vowed never to change their clothes, nor wash nor shave nor comb themselves; he is more of a blessing to his fellow-men than the useless drone, who lives on the work of others and gives nothing in return but arrogant presumption, based on fortune, rank or title inherited from his father.

If this be then the age of rational industrialism, of applied science, how, then, is it that in some industries quality is going down, while prices are soaring upwards?

Here again it is a noteworthy fact that just such commodities as are produced by so-called scientific industries are sold cheaper and are of better quality than ever before, and this cheapening of price or betterment in quality is almost proportionate to the amount of scientific knowledge involved in their production. Let us take, for instance, the chemical and the electrical industries, both based almost exclusively on well-developed scientific data. In both these groups of industries the chemist or the physicist has had full sway, and the engineer has embodied their work in a practical form. Free and rational competition based on intellectual superiority has been their paramount factor of development. Competition based on artificial privileges like labor unions, tariff legislation, have played only a secondary role. While flour, meat, clothing, and houses were considerably less expensive 100 years ago than they are now, we find that acids, alkalies, salts, solvents, dyes and in general almost all chemicals are incomparably cheaper and of better quality than they were in the good olden times.

In some cases the changes are remarkable. For instance, a ton of sulphuric acid sells now at the same price as two pounds of the same article were sold about 150 years ago.

A similar cheapening can be found in many other chemicals, although their demand has immensely increased. Without going to extreme cases, we can state that there has been a steady improvement in most chemical manufacturing processes and that the public at large has had the benefit thereof. The same can be said of the electrical industry.

Compare this with industries which are still under the sway of the rule-of-thumb, which means the rule of the ignorant, or

where competition is based on political protection; you will find that just such rule-of-thumb-commodities, where science plays no role, are those for which the public has to pay the highest price in return for the poorest article. Married men may follow this assertion from butchers' bills to ladies' hats, from house rents to servant girls.

For the poor chemist it is almost an irony of fate that his science, by developing the "cyanide process," made gold cheaper and thereby reduced considerably the purchasing power of his meagre salary. In order to get square he will have to put himself now to the task of helping the engineer in the cheaper production of foodstuffs or clothing, or take a hand in such tax reforms which may bring about a reduction of rent or may lessen other economic anomalies.

Notwithstanding all our progress it is evident that we live in a transitory stage; next to enterprises and industries embodying the highest intellectual conceptions that our century can offer, we find, even in the most advanced countries, examples of conditions of affairs which seem truly an anachronism. This must have impressed many of you who have happened to visit factories or mills where ignorance and greed seemed the two dominant factors, where the class of men and women employed, not to speak of child labor, seemed to have undergone the full curse of their sordid surroundings. Such places are to be found often where the mental condition of the directors does not enable them to go beyond the conception of size and where the whole tendency has been towards more, more, more, instead of towards better, better, better.

How different is this from some of our better engineering and chemical enterprises, where everything bears the imprint of a steady effort towards progress and where employer and employed alike seems to undergo the uplifting force of intellectual aims. Such a happy condition of affairs is most likely to be encountered where the head is himself the scientific pioneer who has built up the enterprise.

Matters are not always so satisfactory where large organizations have gotten into the hand of a board of directors who know little else of the technical side of the business than that it pays

dividends, and for whom the main interesting factor is the value of the shares they own.

Whenever undertakings are ruled by such a class of men, we must not be astonished if their corporation counsel is more in evidence than their chemists or their engineers. What do they care if certain improvements in their processes might net them 5 per cent. more or mean better goods, if, on the other hand, they know that by a clever trick of law they can extract from the consuming public many times more? No wonder, then, if they have less time and less mental fitness for a principle of science or engineering involved in a new process than for a conference with "eminent law counsel." If they cannot alter nature's atomic weights, they may find a way of improving their invoice weights for the custom-house to the detriment of Uncle Sam. I might use for our industries the forceful quotation of Shakespeare in "Hamlet" about the State of Denmark, as long as corporation lawyers of reputation are paid incomparably better and their services are sought for so much more eagerly than the very best chemists or the ablest engineers.

This brings to my mind the case of a company which held a charter to supply a certain city with illuminating gas, and which, after enjoying a fortune-making monopoly for many years, found one day that special legislation had reduced the selling price of their product. Certain again of being able to upset this law, the company entered into long litigation, but, finally, after repeated efforts, had to realize that even its best lawyers could not change matters. From that moment on they began to inquire actively about better manufacturing processes. A friend of mine, who was requested to give his suggestion as to how they could improve their methods, replied as follows: "Up till now your company has been making *law*—now make *gas* and everything will come out all right."

Then again we find that, resourceful as the modern engineer or chemist is, his power is often simply a tool in the hands of ignorant but cunning men. In fact, our modern laws and society insure better reward for cunning or slyness than for true intellectuality.

The very abundance of our natural resources may be partly to blame for this condition of affairs; in other countries, like Ger-

many, with comparatively small natural means, competition shapes itself more towards technical perfection. If we want to learn how to reduce what I would call our "national waste," our German friends can give us valuable lessons. It is significant, too, that in large German engineering or chemical enterprises the board of directors is made up mostly of scientifically trained men—engineers, chemists and physicists. The entrance of the physicist in our industries has not yet become very evident, although in Germany it seems to be the rule, specially in electrical and other enterprises, to give to the physicist as much importance, and even more, than to the chemist; both of these scientific specialists leave the purely engineering problems to the qualified engineer.

The story was told to me how the head of one of the largest engineering firms in Germany won his spurs. Prices of copper were rising beyond precedent, and his merchant business associates insisted therefore that he should buy an amount of copper sufficiently large to supply them for their electric installations for several years to come. In the meantime, prices were going up faster and faster; but this did not seem to disturb the scientific director, who was eagerly following the results of some special research work, giving reliable data about transformers and high voltage transmission. As he understood the law of Ohm, he knew that pretty soon, even if copper was three times higher in price, he could use so much thinner wire and save money in the end. What he foresaw happened; the price of copper dropped suddenly, and Ohm's law triumphed over copper speculators.

All this does not take away the fact that although some industries suffer from brutal ignorance, others have sometimes been handicapped by a too one-sided scientific organization; I know of some instances, especially in Germany, where very respectable enterprises have not utilized their available opportunities to the proper extent, because their scientific managers lacked good business sense. I have seen some industrial enterprises much held back by too much red-tape and a choking amount of paper-wisdom. The most learned man without common sense or practical abilities can accomplish little except disappointments. Here is where the keen business man, with directness of purpose and good judgment will every time show his advantages.

An over-specialized man, whether he be a biologist, a physicist, a chemist, or an engineer, may lack the broadness of conception and action which characterizes truly great men of many-sided development.

Then, again, quite frequently the real field of usefulness of scientifically trained men is much misunderstood. For instance, it is a common mistake, made even by some engineers and physicians, as well as by business men, to imagine that the main work of the chemist is confined to performing chemical analysis. This conception is about as absurd as to think that the main usefulness of an electrical engineer consists in making electrical tests, or that the essential work of the merchant is bookkeeping.

Many a good chemist has been thus prevented from showing his best abilities by the sheer ignorance of those who employed him.

In the development of some of our industries nothing has played such an important role as scientific research work. To those who do not realize this, let me tell that not so long ago I had an opportunity in Philadelphia, to see that old electric machine of Benjamin Franklin, a small revolving glass globe mounted on a wooden frame; this was about as far as electricity went a century ago. Shortly afterwards I was confronted by those gigantic electric installations at Niagara Falls. To those who belittle the value of scientific research I recommend a comparison between this and Franklin's machine, a mere scientific toy, a clumsy affair, that would, at its best performance, and if the weather was not too damp, give off some small sparks; a contrivance so useless in its time and so devoid of apparent practical applications, that if someone had told to a "shrewd business man" of last century what this field kept in store for us, he would merely have shrugged his shoulders in derision. But now behold the hundreds of thousands of electrical horsepower developed in those monstrous generators of Niagara Falls, sensitive as a slender nerve, and yet running with the precision of a watch; distributing power and light to distant cities like Toronto and Syracuse; running heavy railroad trains as surely as the tiny drill of the dentist; converting ores into metals; transforming hundreds of tons of brine daily into caustic soda and bleach; changing mixtures of sand and coal into carborundum; ennobling plain coal

into graphite, or producing from coal and limestone new sources for illumination under the form of calcium carbide; or again fixing the nitrogen of the air on calcium carbide to change it into cyanamide, a most valuable synthetic fertilizer; and at every succeeding year new chemical achievements of the kind are still being brought forward by a set of tireless workers.

Let me ask a fair question to those who underestimate the value of research: Has that stupendous gap between Franklin's toy and the power companies of Niagara Falls been bridged by anything but by scientific research of the highest order?

Some of the better educated people in this country begin to understand more and more the necessity of scientific research. Not so long ago research work was only carried out in the laboratories of universities or in a few highly developed chemical or electrical companies; nowadays we find many intelligently conducted enterprises devoting a considerable annual outlay for systematic research work, where the resources of the chemist, the physicist and the biologist are used to good purpose.

Unfortunately, the scope and method of scientific research is difficult to understand for the uninitiated. Some people have only the haziest conceptions on this subject. Some manufacturers, totally unaware of the requirements involved in this work, in a half skeptical way grudingly conclude to organize a research department, sometimes as a last resort to help them through some difficulties; others do it "to be in style" and simply to imitate their more successful competitors. Frequently they engage a young man with little experience, who, outside of what he studied in the technical school or at the university, has everything to learn, and who, besides that, is usually entrusted at the very start with the most difficult problems. His salary is none too high, and his action is very much restricted; sometimes he is forbidden to study the current practical methods, or so-called "manufacturing secrets," and is thus prevented from getting acquainted with the very problems he is supposed to solve. I have seen other cases where the time of the research chemist was filled with odd jobs of every kind. After a while, when practical results are not forthcoming fast enough, the bookkeeper confronts him with the list of expenses which have been incurred by his work; naturally some comments are ready at hand how the same money spent on

a good salesman would have shown immediate results, and so forth. Things go along that way for a while, until the research department is abolished with the remark: "Research does not pay, we've tried it."

In other cases, where some results are obtained, the matter is taken out of the hands of the chemist before he has had time to fairly try and develop it on a large scale. The subject is now entrusted to the superintendent or the foreman, who seldom is a friend of the scientifically trained man, and nearly always resents anything which might diminish the prestige of "established practical experience." Like in all new processes, defects are soon shown, and in the natural order of things repeated failures and renewed trials on a practical scale are required before there is any possibility of regular utilization. The research chemist is allowed very little intervention at this stage of the work, and after remarks are heard how imperfect the whole thing was "before so-and-so, the practical man, had his say." Finally, initial expenses are charged against the research department, and profits credited to the "practical man."

A research department is a very difficult thing to organize and to run. It is not enough to provide a building and the necessary appliances; it is not enough to provide typewriters, card-indexing systems and office force, and all the red-tape connected with it; it is not sufficient to engage one or more well-behaved university- or college-graduates, with the necessary helpers, and to let them work under an orderly, business-like manager. You might as well try to produce masterly paintings by installing an office management and a well-organized paint and brush department, and a library containing all that has been written on the art of painting next to a splendidly-equipped studio, and then leave out the real artist who will do the painting. Nay, the most important, the almost exclusive factor in a successful research laboratory is the research chemist himself. If he is not a man who has a soul alive with his subject, if he is not enthusiastically imbued with his opportunities, if he is not qualified for his task not only by scientific training but specially by a natural gift of discrimination between what is most important in a problem and what is secondary to it, you might as well fill a hall with the marble

statues of Greek poets and imagine that they will write poetry for you.

Then if you find the man who has all the true qualifications, you may still paralyze his action by too much red-tape, too much interference in his work. A good research chemist will do more and better work with pots and pans from the "ten-cent store" in a shed or in a barn, where he is his own master, than in a splendidly-equipped laboratory where he gets irritated and interfered with by others who do not understand him.

I sometimes doubted whether it was really worth while for a young man to take up research work single handed, when so many people with abundant facilities were at work. What show, for instance, does an organic chemist have in studying a problem for which, in Germany, some large chemical companies employ hundreds of research chemists? To this I can answer that some of the most striking examples of successful research were the result of privately conducted work with modest means; in fact, I know of several instances where a research chemist who had created himself a reputation by work carried out privately under adverse circumstances showed disappointing results as soon as he became part of a vast organization. Even if you have the best-qualified research chemists, do not expect immediate results. Do not forget that problems appearing most simple require considerable time before they are thoroughly studied. Even in successful cases it may easily require many many years before a subject is so thoroughly elucidated that it can be taken up in practice.

Research is what gives a young man of strong individuality a chance to compete with those big industrial consolidations, the trusts, who, like elephants, look more imposing by their size than by their agility or perfection, and who, like that pachyderm, have many vulnerable spots, and are just as much handicapped by their lack of flexibility and by their ponderosity. Some steel manufacturers may be unable to think about anything but tonnage, and yet the work of some chemists has already indicated that the quality of steel of the future, or of its alloys, may be improved to such a degree that probably the average steel of today will look to our children as brittle and imperfect as pig-iron appears to us. Neither should we lose sight of the fact that even

to the most exclusive mechanical enterprises there is a chemical side, although the importance of the latter may not be apparent to the man who is not a chemist.

Let me give also a warning to such manufacturers who try to secure only by uncompromising secrecy the money-making end of their industries.

As far as my experience goes, exaggerated secrecy is very often an indication of lack of knowledge, of industrial feebleness and incompetency; a miser is most of the time a man of small means.

If chemists had been holding their results from each other we would still be in the dark ages of the alchemist. No secrecy, however jealously carried out, can outweigh enlightened research work protected by wise patent legislation. If our patent laws do not protect enough, then our prime duty becomes to change them until they answer their purpose as defined by the Constitution of the United States. The care with which patent laws are administered is a direct measure of the industrial importance of a country. Piracy cannot flourish, either on the seas or in intellectual property, if ethics of justice and equity can be made to prevail.

Every recorded success of the scientist or the engineer is an additional evidence that ignorant greed and brutal rapacity cannot forever have full sway in this world, and that the rule of the sly and the shy leads to the abortion of progress. Furthermore, the results of their work, which bar out "chance," "luck," or "happenings," is their most eloquent language to convince their fellow-men that if law-makers may still think that laws are made or unmade by them in Albany or Washington or Harrisburg, there is at least one law which cannot be amended; at least one law which even the cleverest lawyers cannot make to be interpreted in two different ways; a law which rules all men, large or small, poor or rich, to whatever nation they may belong; a law which rules the dead and the unborn as well as the living; a law which requires no supreme court to test its validity; a law that cannot be trifled with, which nobody and nothing can escape—the great, unchangeable law of nature, which rules the universe, mocks at men-made statutes and ordinances, and upsets and destroys everything which comes in conflict with her; the rigidly enforced law which tries to teach us our mis-

takes by suffering, by misery, by industrial or political crisis, by unhappiness, by war, so as to awaken us from our ignorant sleep, to show us our misguided aims and to command us to prepare a sounder, a happier condition for our children and future generations, while building up, during the trend of centuries, a slowly rising foundation for a higher humanity, a more god-like race.

An address delivered at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 7, 1910, President L. H. Baekeland in the Chair.

THE CONSERVATION AND UTILIZATION OF NATURAL SOURCES OF POWER

By JOHN H. FINNEY,
Secretary of the Appalachian National Forest Association.

Mr. Chairman, and Ladies and Gentlemen:

If the man who makes two blades of grass grow where only one grew before is so commended, how much more does he deserve commendation who makes a blade grow where none grew before? Of how much greater benefit to humanity becomes the work of such men as are before me today who, through skilled science and patient research and technical skill, are building on new foundations, in new ways, new enterprises and are thereby bestowing upon mankind the blessings of new material and new methods of making old material to the noteworthy advancement and benefit of the whole world.

It has struck me with force, since talking over with Dr. Richards the present status of the art, what little realization the average man has of the marvels of the electrochemical industry, its tremendous advance in recent years, its marvelous accomplishments to date, its assured and brilliant future. It was a revelation to me, in fact, and addressing the men of achievement who are thus building to the betterment of mankind, and building always along constructive instead of destructive lines, I feel that a speaker on "Conservation and Utilization" is not only in the house of his friends, but that the real meaning of conservation and utilization must strike them with especial force and reasoning. This is all the more gratifying because the topic assigned to me was originally one that was to be handled by a man so eminent, and is so large and vital and far reaching, that its handling along the lines laid down by your distinguished secretary carries not alone high honor in taking this speaker's place, but considerable responsibility as well, if the topic is to be worthily interpreted.

I bring to my task much earnestness and deep conviction, and I hope that you will find in the presentation and suggestions that are to be offered some real helpfulness and merit towards the solution of problems that very intimately concern not alone your profession and industry but the entire nation that is, and the infinitely greater nation that is to be!

While conservation did not have its birth at the governors' conference called at the White House two years ago by President Roosevelt, it received a mighty impulse there, however, for gathered in what has been called a directors' meeting were the governors of 44 States, with their advisers, and with a large representation from civic and professional life (I see some of them here today) in a discussion on the natural resources of the Republic, that will live long both in the minds of those privileged to attend and on the pages of the nation's history.

It was the first gathering of the kind in all history, and the inventory then taken is a striking one from two standpoints: First, our marvelous stock of resources in waters and soils and minerals and forests, and, second our almost criminal misuse of them all.

Let me define conservation: Conservation has been aptly put as "the application of common sense to common problems for the common good." It is more than that, for it is the application of "common honesty to common problems for the common good—honesty to one's self, to one's children, to one's country." As it has been forcefully put by another eminent writer, it is "racial conscience," and an aroused conscience.

Conservation is a moral question—a moral issue, indeed—greater than any man or set of men who stand either for or against it. It is even something more than that, for conservation means in its final analysis the "equality of opportunity" for all future time, for all those who are to inhabit the earth after us.

This definition of conservation, and the added qualification that utilization shall be "wise utilization," serves to put the whole question upon the high moral plane which it is entitled to occupy and serves to show that upon us as individuals, acting as honest trustees for the future, there rests a heavy burden of responsibility that as honest men we cannot well evade.

If this definition is true, it is principally because of the work

and life of one man—that man is Gifford Pinchot—a mighty force for righteousness, than whom, either in or out of office, no more useful citizen of the Republic exists, the man who is enough of an idealist and dreamer to look ahead for a thousand years and is yet intensely practical in questions and problems affecting the immediate present. I am but a poor substitute in handling a topic which he would have presented, had he been at home at this time, and which he could have handled so well.

Again, if this definition is true, it is none too soon that the nation is beginning to realize (as your Society has done by some admirable resolutions recently) that there is underlying the whole conservation movement not only hard common sense, but that the principles of conservation, namely, "wise use," are absolutely sane and imperative; that the wantonness and waste and prodigality that have characterized our every use of our natural resources must stop, and must be replaced by a careful economy, must, indeed, bring about a radical change in the nation's habits and thoughts and practices if the nation is to endure throughout the ages.

And this is true, in spite of certain setbacks the movement has recently had (it is perhaps not necessary to go into details with men who read the papers), for it may be absolutely put down as a truism that the leaven of civic righteousness is at work as never before on any single question or problem, and at work throughout the entire nation; the aroused national conscience will not be stilled until conservation laws and conservation *action* are written in both the nation's statute books and in the hearts of the people.

To get down to my subject (which I do not intend to handle in a purely technical way)—"The Conservation and Utilization of Natural Sources of Power"—let us take stock of what the nation has in such sources of power.

They are conveniently and appropriately divided into two classes:

1st. The Exhaustible Sources.—In this class we must put the following: Coal of all kinds, oil, natural gas, waste gases, peat and wood.

2d. The Inexhaustible Sources.—In the latter class we will place manual labor, animal power, wind power, solar heat and

water power. Thus differentiated, we can more readily grasp the importance of a national inventory in these things that will fix firmly in your minds the nation's supply.

Of the exhaustible class, our most important item is coal, and some statistics are absolutely necessary. The area underlain by workable coal beds in the United States is 496,776 square miles, 480 square miles of which contains the entire anthracite coal fields of Pennsylvania; the bituminous coal fields are estimated to be contained in an area of 250,000 square miles; a grade of coal between bituminous and lignite, designated as sub-bituminous, is estimated to be contained within an area aggregating 97,636 square miles; the lignite area aggregates 148,609 square miles.

Within recent years the Geological Survey has worked in all of these coal areas, and very careful estimates have been made to ascertain how much of the supply is easily available and how much is either not available under present mining and market conditions, or is available with extreme difficulty. These estimates show that the quantity of coal contained within the known area of the United States when mining first began was 3,076,204,000,000 tons. Of this quantity a little less than two-thirds, or substantially 2,000,000,000,000 tons is considered as coal that is accessible and minable under present conditions, the remaining one-third being considered as non-minable or accessible with extreme difficulty. The 2,000,000,000,000 tons above mentioned includes the lignites and sub-bituminous coals of the Western States, about which there may be considerable doubt as to their availability either at present or in the near future, certainly as to at least one-fourth of this supply, and if this fact is taken into consideration the easily accessible and available coal is reduced to, approximately, 1,400,000,000,000 tons.

Coal was first mined in a commercial way in the Richmond basin in Virginia. The first actual record of the production of this field was in 1822, when 54,000 tons were mined. In 1820—two years before—365 long tons of anthracite coal were mined, and from these small beginnings of less than a century ago the production of coal has increased until in 1907 the total output of anthracite and bituminous coal aggregated, approximately, 500,000,000 tons.

The aggregate production to the close of 1907 has amounted to 6,865,097,567 short tons. Up to the close of 1847—or in twenty-five years—the total production of coal in the United States was 27,700,000 short tons (say, 1,000,000 tons per year), and since that time the drain on the supply has practically doubled with each decade.

Let us consider the duration of supply, assuming that the total reserve is 1,400,000,000,000 tons. We are not warranted in the assumption that a constant output has been reached; on the other hand, the adoption of the flat rate of annual increase of 7.36 per-cent would involve the improbable assumption that the marvelous record of the past will be maintained in the future, and that the production would, approximately, double every decade.

Using the waste allowance, however, on the basis of this constant rate of increase in production, the available supply would be exhausted in 107 years. Against the flat rate of increase it might well be contended that just as the rate of increase in population tends to diminish, so this rapid increase in per capita consumption of coal mining cannot persist, and a constant annual production can therefore be reached. It is significant, however, that figures set fifty years ago by statisticians for the probable constant annual production of coal in England have already been exceeded by over 160 percent.

I want to take up here a few facts about waste in mining. The principal loss, of course, occurs in the actual mining, and the greatest item of waste in mining is for supplying pillars for roof supporting. There are no exact figures as to this waste, although it is estimated that it amounts to 50 percent. In the earlier days of the anthracite region only about 40 percent of the coal was extracted. Today it is reported that under the admirable recommendation of the Anthracite Coal Waste Commission, the recovery from the Wyoming region is 60 percent to 64 percent, and in the Lehigh and Schuylkill regions about 56 percent. I believe that this is going to be improved somewhat in the anthracite region, but I doubt that much can be done in the bituminous region in the face of over developed properties, keen and ruinous competition and selling prices that are much too low.

Another serious waste in bituminous coal mining is, like the culm in the anthracite fields, represented by the slack coal neces-

sarily or unnecessarily produced in mining. The large part of the waste of slack could be prevented by briquetting, and it is interesting to hear of a recent invention for burning culm and slack which is going to permit the use of both this slack and culm, if the inventor's claims are substantiated. There is brought up here, naturally, the question of waste gases and the grave inefficiency of our present use of coal in boilers for the generation of power; and just a brief statement of these preventable wastes should demonstrate to such a body as this the tremendous field there exists for engineering skill in working out plans that will make for greater efficiency in both mining and use. For instance, we are far behind Germany and other foreign countries in adopting economies resulting from the coking of coal in by-product ovens. In Germany, at the present time, little or no coke is made except in retort ovens. Up to the close of 1907 the total number of this type of ovens operated in the United States was 3,892, while the number of beehive ovens in operation in that year was 94,746. The retort ovens produced 5,607,899 tons of coke, or about one-seventh of the product from beehive ovens, and the value of the by-product obtained in the retort ovens amounted to over $7,500,000, or a little more than one-third of the value of the coke produced by them. Some utilization of waste gases is in evidence here and there, but the economic refinement common in foreign countries is almost wholly lacking here. We could almost double the life of our coal supply if we were to employ internal combustion engines instead of steam engines.

Next in importance as a source of power is, perhaps, natural gas. The total area of the natural gas field in the United States amounts to a little over 10,000 square miles, with a production in 1907 of nearly 400,000,000,000 cubic feet, valued at $52,000,000. Dr. White, State Geologist to West Virginia, says, "not less than 1,000,000,000 cubic feet of gas are wasted every 24 hours," and while undoubtedly the larger part is wasted in the production of oil, it is possible to save a large portion of this waste by a care that seems to be entirely lacking on the part of the petroleum operators. Any effective measures must have the co-operation of the natural gas and oil collecting companies, backed up by stringent regulations on the part of the various States. Some of the States—Indiana, Ohio and Pennsylvania—have such laws.

Taking up next the matter of petroleum, the known oil territory of the United States comprises 8,450 square miles. The starting point of the industry was right here in the Pittsburg district—at Tarentum. I am not going to talk to a Pittsburg audience on that phase of it, but from the small beginning of 50 barrels made by Samuel Kier from his salt wells in 1859, the production has grown to 166,000,000 barrels in 1907, with a total value of $120,000,000. The waste in the petroleum industry comes principally from its wrong utilization. In the face of the approaching exhaustion of our petroleum industry, it would be well to limit the use of petroleum to the purposes for which it is necessary and for which no substitute can be found. It is for this reason that it can be well said that the use of nearly 19,000,000 barrels of crude oil burned as fuel in locomotives in 1907, at a price which brought not more than a 100th part, and perhaps as low as a 1,000th part of its value for high-grade petroleum products, and also our tremendous export business in oil, are serious economic mistakes.

Peat, as a source of power, has but recently attracted attention in this country. It has long, however, been used in Northern Europe, and recent developments in the utilization of lower-grade fuels in producer-gas engines and the very successful use of peat for the generation of fuel and producer-gas in Sweden, Germany and Russia, should make a marked impression on us here, for these developments clearly show the possibility of using peat as an auxiliary fuel with profit.

We have in the United States a swamp area of perhaps 140,000 square miles. If we can assume that 8 percent of this area will have peat beds of good quality, we have over 11,000 square miles of peat, averaging at least nine feet in depth, and containing 200 tons of dry fuel per acre for each foot in depth; we thus have a total of nearly 13,000,000,000 tons. If converted into producer-gas by the more recently discovered processes, this would give us some 619,257,511,000,000 cubic feet of producer-gas, with a calorific value of 145 B. T. U. per cubic foot. Assuming 1.5 percent of nitrogen as an average content of the peat, which is low, since many analyses show more than 3 percent, 100 pounds of ammonium sulphate per ton of peat treated in the gas producer could be obtained. On this assumption, there is stored

up nitrogen enough in the peat to supply at least 644,400,000 tons of ammonium sulphate, having a value of $56,732,400,000, in addition to the gas produced; and a conservative estimate of the gas, based on 2½ pounds of peat per horsepower hour, which is quite possible in properly designed gas producers, shows that we have stored up in the peat beds of the country energy sufficient to develop 10,310,860,800,000 effective horsepower hours, or, put another way, 1,000,000 horsepower for 2,000 years.

It is hardly proper to classify wood as a source of power. It has its limitations here, just as it had in 1732 in England, when the iron industry faced a crisis due to the exhaustion of the timber supply. Today our forestry condition is a matter of grave concern to the whole nation, and I am going to stop right here on the question of wood, because if I get started on forestry I will not have time to talk anything else. It may be said in passing, however, that the whole question of water power is so intimately tied up with the forestry question that it is difficult to separate the two things.

I have been working for the Appalachian White Mountain forests for many years. As you probably know, our Southern water powers are most seriously menaced by the national neglect and folly that has disregarded so long the necessity of protecting their headwaters. I will consider this a little later on.

As a source of power, wood is now unimportant; and while it could go into the inexhaustible class, and could gain in importance by proper forest conservation applied generally throughout the nation, its use as a fuel, except for family purposes, would be the utmost folly.

I have not, in this discussion, taken up the question of resources in Alaska in these various items. Alaska is a treasure house about which too little is known, by the general public, at least. It seems to have been pretty thoroughly investigated by some people who proposed to exploit it; but it is known, of course, that there is a large supply of coal, a large supply of peat (which is found in every part of Alaska, except in the high ranges), and there are strong possibilities that oil occurs in considerable areas, although no profitable oil pools have yet been shown.

We come now to the Inexhaustible Sources of Power. We will consider manual labor first. The old Biblical injunction, that a

man shall earn his bread by the sweat of his brow is true and always will be true. We shall always have the hewers of wood and the drawers of water, and can always count on a definite supply. It is a hopeful sign that it is a better supply, better in quality than it used to be, and this improvement is likely to continue as the race advances in things that make for right living and right thinking. There has been remarkable progress in the laboring class towards better living and better efficiency. But a point I want to make here is that we as a nation are still careless of the nation's vitality, and this is particularly true as it applies to our safeguarding against disease and accident.

No plan of conserving the natural resources can avoid the larger problem involved in conserving national efficiency. Protection against accident, forest fires, floods or pollution of streams, prevents not only loss of property but loss of life. The prevention of disease, on the other hand, increases economic productivity and makes for that greater national efficiency that is even more vital to the nation than its physical resources.

Animal power is not now important except for haulage and tillage problems, and since the advent of the automobile and the steam and electric-power plough, with the farmer as purchaser and user of both, the horse is practically dropping into disuse, save for pleasure purposes.

Wind engines hold a minor place, largely as engines for pumping water, which is perhaps to be their principal use in the future. No large powers seemingly are likely to be developed from this source.

The obtaining of power from the sun's heat is nothing new. Nature has been doing the same thing from the beginning of the world. The great sources of power in nature, whether they be waterfalls, or winds, or waves, or even the energy stored up in coal or other fuels, can one and all be traced back to the heat of the sun. Lord Kelvin estimates that the sun radiates an amount of energy equal to 350 sextillions horsepower, or, in other words, each square foot of the sun's surface radiates 7,000 horsepower. As for the part of this heat received by the earth, its section is such that it receives 1/2,700,000,000,000 of the whole energy radiated by the sun, or, concretely, 130,000,000,000 horsepower. Buchanan determined that under the cloudless sky of

Egypt each square meter of surface was receiving 1 horsepower when the sun was shining directly upon it—that is to say, 1 horsepower per each 10 square feet under the equator, while the sun shines, which would probably not average more than a mean of 1 horsepower for 50 square feet all over the earth.

Now Egypt has no better sunshine than many parts of our own country, where the sun shines almost continually, and with an available heat energy in many parts of our country of from 2 to 10 horsepower per 100 square feet, or 800 to 4,000 horsepower per acre, solar heat is certainly entitled to consideration, and to deep engineering thought against the time when we shall need it all over this country. You are, of course, familiar with some of the devices that have been brought out by Ericsson and others for the utilization of this heat.

Ericsson's experiments are perhaps the first valuable ones recorded, although previous to Ericsson, Mouchat constructed in Paris a solar motor using mirrors, which focused solar heat upon a steam boiler. Another type of solar motor, not so familiar to the general public, consists of a boiler exposed to the direct action of the sun's rays, and an engine and a condenser. This employs a liquid which has a low boiling point, such as ether or ammonia, which, placed in the boiler, will, during the middle hours of a bright day, afford a sufficiently high vapor pressure to operate the engine. Another plan is the indirect storage type, which has attained some striking results, in which the heat is stored before it is changed into the form of mechanical motion. This is well shown in a recent publication in the *Engineering News* of May 13, 1909, in which a concrete example is given of the experimental work done by Willsie and Boyle.

Their experiments involve the collection of solar heat from an extended area and the bringing of this heat to a boiler, it being remembered that a pound of water raised one degree in temperature has stored up as much energy as a pound of water raised to a height of 778 feet. The intermittent solar heat under their plan is absorbed and collected by some fluid, as water, circulating in the coils of the heater. The solar heated water is then stored in an insulating tank and drained uniformly and continuously therefrom, being made to give up its heat by circulating about a boiler containing some volatile liquid, as ammonia

or sulphur dioxide. The vapor generated by this heat, after operating the engine, is condensed and returned to the boiler to be used again. The water, after giving up its heat to the sulphur dioxide, is sent through the solar heater to again collect the heat in the sun's rays.

Under their plan, the cost of the heater is about 25 cents per square foot of the surface exposed, with a possible reduction to 15 cents, and it is shown that this heater on the earth's parallel of 34 degrees receives during a June day about 2,300 British thermal units per minute per square foot and about 1,600 in December. It is also found that a sulphur dioxide engine, working within the range that can be had from this heater, requires about 30,000 heat units per horsepower-hour, or 72,000 heat units per horsepower for a 24-hour day, making 260 square feet of heater surface per horsepower for a 24-hour day. It is interesting to know also that the sulphur dioxide engine has been brought to greater perfection in Germany than elsewhere. A 50-h. p. engine has been running in Charlottenburg for some four years. There is installed at the Berlin Electric Works a 175-h. p., and a 450-h. p. engine in the Machinen Fabrik Geb. Sulzer, all showing remarkable efficiency and satisfaction, it is said.

The cost of a sun-power plant, under this plan, is given as $164 per horsepower, which includes the heater, storage, engine, pumps, vaporizer, liquid sulphur dioxide and emergency steam boiler, which would compare with the $40 to $90 per horsepower as the cost of a steam-power plant; that is to say, that the cost of a sun-power plant is from two to four times that of a steam plant. But a comparison of cost per horsepower-hour in a 400-h. p. steam-electric and solar-electric plant shows a marked saving in favor of the solar heat plant, in which the cost of one electric horsepower hour is given, with the steam plant at $40 per horsepower, as 2.078 cents, as against 0.610 cents for the solar plant costing $164 per horsepower; in other words, on this basis a steam plant must obtain its coal at 66 cents per ton to compete with a sun-power plant in districts favorable to the latter, and the above sized plant would pay for itself in less than two years. There is another suggestion that might be made, *viz.*, utilizing this solar heat by the use of thermal couples. Dr. Richards has such a couple in his laboratory, utilizing Bunsen burners, and

getting from a very small unit a watt-hour of energy per cubic foot of gas. It would seem that a thermo-couple employing the sun's heat might lead to extremely interesting results; and it might be said in passing, to go back a little, that this same device might with propriety be considered in connection with the utilization of waste coal gases. There is no doubt but that a source of so much power must finally be utilized, and that some way will be found in which to do it readily and economically; but *until* it is done, we must consider water power as the principal and most important source of natural power for the future, and it is to this item that I am going to devote the balance of my talk.

I should like to define my own position in respect to water power. It is extremely desirable that the fullest development of these powers should be made, and as promptly as possible. That is conservation in its truest sense; but development should also mean *wise use,* and wisdom in dealing with them must consider many things, such as:

Wisdom must recognize vested rights of property, even under a new dispensation later referred to.

It must recognize that capital in large amounts will be required for development.

It must recognize the rights of capital to a proper return on a properly financed and managed development.

It must insist on proper development, along the best engineering lines, and *complete, i. e., not partial, development.*

It must safeguard the rights of the nation and the State and the community served or affected by it.

With this as a preliminary and as a guide for our future handling of this problem, it can be said that the position of our country in respect to water power is neither good nor clear; probably no problem affecting so intimately so many people and interests is in such chaotic condition, both in respect to ownership and rights and laws governing such owners and rights. We are, in fact, in about the same condition in this respect as we would be in respect to transportation were our laws governing transportation of the character that prevailed prior to the time of the steam railroad. In short, we are just beginning to meet a real and tangled problem, and are many years behind other progressive nations in formulating a satisfactory solution.

The sole source of fresh water is rainfall and snow; from this source our running, standing and ground waters are derived. We have a mean annual rainfall of 30 inches, and the quantity falling on the land averages about 200 trillion cubic feet per annum. In volume this equals 10 Mississippi Rivers. Of the total rainfall, over one-half is evaporated, and about one-third flows to the sea. The remaining sixth is either consumed or absorbed, and about one-third of the run-off, or, say, one-tenth of the total rainfall, passes through the Mississippi River. The 70,000,000,000 cubic feet of run-off is available for water power, water supply, irrigation and navigation.

The theoretical power of the streams in the United States is recorded by Leighton as 230,000,000 horsepower, and the amount available at a cost comparable with that of steam installation is estimated by the Geological Survey as 37,000,000 horsepower, and the amount prospectively available at from two to five times that amount. The larger amounts, of course, would mean catchment basins for the storage of storm water.

Assuming that we have 37,000,000 horsepower available for economical development, this amount exceeds the entire mechanical power now in use in the country; and this is an asset of the highest importance, not alone to the country, but to the electrochemical industry particularly. The water powers of this country have a higher ultimate value, therefore, than is generally conceded to them. They are certain to have a commanding effect on the material progress of this republic. The demands of the people for mechanical energy are every day becoming more general and more acute, and with the growth of this demand there must inevitably follow an increasing interest in the source and development and control of this energy.

As has been said, the condition of our country in respect to water power is not good. The chaotic condition referred to later will be understood when we consider the complexity of ownership and rights. Riparian owners in some States own to the middle of the stream and are entitled to use the water; in other States riparian ownership stops at high or low water mark, and the State owns the waters; then we have joint ownership of States in boundary waters and government control of navigable waters (though they may be individually or State owned). These cases,

brought out in a summary of the situation which even now may not be complete (for I am no lawyer) are:

1st. Individual ownership of riparian and water rights to middle of non-navigable streams wholly in one State. It would seem here that the owner can, through his own initiative or through a corporation, charter, develop and control absolutely his power if used for his own purposes, and would come under State restrictions if a public service is done within the State, and should come under interstate control by the Federal Government if commerce is had between two States.

2d. Individual ownership of riparian and water rights to middle of non-navigable streams lying between two States. Seemingly the same inherent rights obtain as in the former case.

3d and 4th. These are problems having the same conditions as 1 and 2, except that the State owns the waters, as in New York and Oregon, for instance, in which, as owner, it can dictate control and franchise and royalty charges.

5th. Covers water powers in the government domain, as in the national forests in the West, in which the nation is riparian owner (and as such is amenable to State laws, presumably), and this class of power is the subject of fierce controversy at the present time, with no definite solution in sight.

As all the above refer to powers on non-navigable streams, we have as a further complication:

6th. Power on a navigable stream from constructive works in improvement of navigation, as on Muskingum and Green Rivers, and proposed for certain other works on the Hudson, near Troy, and on the Mississippi, between St. Paul and Minneapolis.

7th. Power on a navigable stream developed by private enterprise in co-operation with the government in improvement of navigation, as at Chattanooga.

8th. Power on a navigable stream developed wholly by private enterprise, in which the government permits the improvement to navigation and exacts a ship-lock, as at Keokuk and elsewhere.

Around all of these situations there is thrown the added difficulties of State or States owned waters, individually owned waters, etc., until one's brain actually whirls.

Each particular case above named actually exists, and each case seems to require and demand different treatment along lines that

are not as yet well formulated, and are extremely difficult to satisfactorily treat under our form of constitutional government.

This makes, as you see, a complex and serious problem, because in its solution we must get a new view point and reach conclusions that are at variance with our old conception of individual independence.

As Mr. Leighton has lately put it: "Complete individual independence is possible only where a man is isolated or where his interests in no way conflict with those of other men. The independence gained by us at the time of the Declaration of Independence was largely national; each colonist was quite as dependent upon the other after the declaration as he was before, and, as it soon proved, each colony was dependent upon the other. Thus arose the Federal Constitution, and ever since its adoption laws have been passed by the States and nation that have progressively deprived the citizen of his individual independence—and necessarily so, for the common good must always be superior to individual interest. This point is made in order to make clear the proper point of view with reference to the water power problem. It is a consequential problem, the direct result of progress and achievement, and to solve it we must make another raid upon the province of individual independence. We must change our habits of thought with reference to water powers, and include them within the domain of public utilities to be subject to control for the common good."

We have from early times been accustomed to consider all water power as a private investment for a private purpose. This was quite the proper conception of a power located at a given site and developed for a specific purpose at that site, to be used as wastefully or as efficiently as the owner chose, just as he would any other piece of private property.

Electrical transmission worked a fundamental change in the aspect of water power. A water power now is, or may be, the center of a common source of energy in a radius of 150 to 200 miles or more, serving many towns, communities, even many States. It is in the public market and has developed a large public use, just as a railroad, passing through a given section of the country, becomes a common carrier and develops a public use. No one will contend that public interest in a common agent

of transportation is greater than that in a common agent of production. One is merely the complement of the other in industrial progress. The two are identical in economic value; but whereas our appreciation of the public utilities in transportation agents has been reflected in sundry legislative acts, we are seemingly almost entirely unprepared to meet the new condition with respect to common agents of production.

This is not a satisfactory condition, either for the people who want power, and must finally have it under conditions that impose no unnecessary burden on them, or for the capital that wants to develop it, and while we are prone to disregard what other nations are doing, we can well afford to review and consider some European legislation, and in the study and necessary adjustment of our own problem to ascertain what these older countries have found it necessary to do.

In Switzerland, a water-power country of the first rank, previous to October, 1908, each of the 25 cantons had jurisdiction over the waters within its boundaries, and each canton regulated them in accordance with diverse principles. The advisability of placing control of waters and powers under the federal government was the subject of careful investigation by the General Council from 1892 to 1894, and while not found advisable at that time, the council nevertheless recommended to the cantons the incorporation of uniform laws based on the following principles:

1st. All water powers shall be considered as of public utility.

2d. Compulsory mutualization of all water-power interests along a watercourse with respect to the utilization of hydraulic energy.

3d. The right of the cantonal authorities to investigate the industrial value of proposed enterprises and to base their decisions relative to applications for power sites on the results thereof; also, their right to reserve to their own use, or that of an interested commune, any power site.

4th. In case of damages sustained by the owners of water-power plants by reason of changes made in the regimen of watercourses in the public interest, said owners shall not be entitled to indemnity.

5th. The limitation of the term of the concession to a fixed number of years, with clauses of forfeiture in case of non-utiliza-

tion, or of redemption by the canton. The above procedure of the Federal Council shows clearly that the need was felt at the time for uniformity in administration of water powers within the Republic, but that public opinion had not yet united in favor of centralization to a degree sufficient to give the members of the council confidence in supporting so radical a measure. A little more time and a little more difficulty with the prevailing conditions was apparently necessary. It required fourteen years more of thought and experience to convince the people of the Swiss Republic that necessity and not legal precedent governs the proper course of procedure with reference to water power. On October 25, 1908, by a popular vote of 292,997 against 52,180 in opposition, an amendment to the constitution was adopted which provides for the centralization of authority over water powers. The amendment reads, approximately, as follows:

> The Federal Congress shall have supervision over the development of water powers, shall make provision for the disposition of water rights concessions, and shall regulate the transmission and distribution of electrical energy, so far as may be necessary to protect the public interest and to provide for the proper development of such resources; all water rights to which the terms of the Federal law do not extend shall be under the jurisdiction of the cantons, which shall dispose of the concessions, regulate the same, and impose taxes and fees for their use, but such regulation, taxes and fees shall not be so severe as to prevent or inhibit the development of water powers. The National Government shall regulate and dispose of concessions for powers located on intercantonal and international boundary streams and shall determine the taxes and fees to be imposed thereon, after hearing has been granted to the cantons interested, but such taxes and fees shall be collected by the cantons. No power located on a stream within the Republic shall be transmitted to a foreign country, without the consent of the Federal Council. The provisions of Federal law shall apply to water rights concessions already existing, except in cases specifically exempted therefrom by law.

Both Italy and France have enacted vigorous and well considered laws dealing with this problem. Italy's organic law, excellent at that time, dates back to 1884 and has been later supplemented and strengthened by laws adopted in 1898. The French situation is somewhat similar, though in no wise as serious as in this country, but their laws are excellent and liberal, though safeguarding the varied interests involved.

I can lay down no hard and set rules to govern our own future dealings with this power problem—it is a large problem, that urgently calls for solution along proper lines, that requires states-

manship and patriotism and unselfishness in large and generous measure, but some suggestions may with propriety be made as a guide to nation-wide and uniform action.

They are these:

1st. A keener appreciation by the nation and the State of their legal rights, and of the unwisdom that exists in the almost total disregard of the duty that should properly safeguard for the people these legal rights.

2d. A liberal and practically unrestricted national or State franchise for new enterprises, limited as to life, but this limit to be so fixed as to cover fully the life of the bonds, which franchise shall be renewable along equitable lines for further definite periods, if properly handled and if not in conflict with public good or public necessities then existing.

3d. Rate regulation, by the State, of State corporations, through charter requirements or public service commission (such as New York), with control of capitalization.

4th. Rate regulation, by the Federal Government, of interstate corporations, with control of capitalization.

5th. Declaring transmission lines of public service companies to be common carriers, whether interstate or intrastate.

These suggestions seem to me to be practical, equitable and neither socialistic nor unattainable.

The last suggestion only requires comment. A public service corporation supplying power over wide areas, in one or several States, from either a common center or a group of centers, feeding into a common network of distributing wires, either is, or can become, a natural monopoly; it can be a benevolent or grinding one, as conditions, or opportunity, or disposition allow, and this condition should not be permitted to exist; and for the additional reason that it may bottle up, so to speak, every other water power within its zone of influence until such time as it itself is ready to buy additional powers.

It seems, therefore, that if transmission lines are declared common carriers, forced to accept electrical energy for transmission, under conditions that insure a fair return for the service, it would open wide the development of many powers now dormant and

doomed to remain so for many decades, would increase the available supply, would make desirable competition, would, in short, be true conservation.

Our little Forest Association, in its work for the establishment of the Appalachian-White Mountain National Forest, has been doing a patriotic work of high value. It is fighting still for this necessary legislation, which in its truest and best sense is a national duty, owed by the nation to itself. Its work has been inspired by unselfish devotion to a cause that is of paramount importance to the whole nation. It has found added inspiration in these words of Mr. Roosevelt, spoken two years ago:

"The time is coming when a man will be judged not by what he has accumulated for himself from the common store, but by how well he has done his duty as a citizen, and by what the ordinary citizen has gained in freedom of opportunity, because of his service for the common good."

Conservation is, indeed, "service for the common good," and I commend this passage to you as a guide in your future actions and thoughts concerning it.

Conservation calls for and demands an arousing of the individual conscience such as will put each individual to work in its interests, and this revival must spread through the length and breadth of the Republic. Continued indifference to this call will permit and finally establish complete control by monopolistic capital. The door of opportunity is fast closing; it is, to me, unbelievable that we should be willing to stand by and see it forever closed.

Arouse Ye, my Brethren! Only thus can Our Nation consist of Free and Equal Citizens having a Birth-Right of Free and Equal Opportunity.

An address delivered at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 7, 1910, President L. H. Baekeland in the Chair.

WHAT ELECTROCHEMISTRY IS ACCOMPLISHING.

By Joseph W. Richards.

Ladies and Gentlemen; Guests of the Society and Fellow-Members:

As the Secretary of the Society I may assume to greet you on behalf of the Society, and to thank you for having come so far and taken of your valuable time to attend this Public Meeting.

My theme is to depict for you, as clearly as I may be able, the part which electrochemistry is playing in modern industrial processes. I have no exhaustive catalogue of electrochemical processes to present, nor columns of statistics of these industries; but my object will be to classify the various activities of electrochemists and to analyze the scope of the electrochemical industries. And since electrochemical industries have developed in almost all parts of the world except Pittsburgh, I will endeavor to bring to your view by means of pictures, taken from actual photographs of plants in operation, the reality and actuality of the large and important electrochemical industries.

SCOPE OF ELECTROCHEMISTRY AND ELECTROMETALLURGY.

Chemistry is the science which investigates the composition of substances, and studies changes of composition and reactions of substances upon each other. As an applied science, it deals chiefly with the working over of crude natural material, and its conversion into more valuable and more useful substances.

Some common examples, to illustrate this statement, are the conversion of native sulfur into sulfuric acid, the manufacture of soda and hydrochloric acid from common salt, the conversion of phosphate rock into super-phosphate fertilizer, *etc., etc.* Several pages would not suffice to merely catalogue the great variety of chemical industries; immense amounts of capital are invested in

them, and they are some of the most fundamental industries in their relation to supplying the needs of a rapidly advancing civilization.

Metallurgy is the art of extracting metals from their ores, and of purifying or refining them to the quality required by the metal-working industries. It is a branch of applied chemistry. The metallurgical industries form a highly important part of our national resources; on them we depend for iron, steel, copper, brass, gold, silver, lead, zinc, aluminium, *etc.*, in fact for all the supply of metals used in arts and industry.

Electrochemistry is the art of applying electrical energy to facilitating the work of the chemist. It is chemistry helped by electricity. It is the use of a new agency in accomplishing chemical operations, and it has not only succeeded in facilitating many of the most difficult and costly of chemical reactions, but it has in many cases supplanted them by quick, simple and direct methods; it has even, in many cases, developed new reactions and produced new materials which are not otherwise capable of being made. A few examples will illustrate these points: Caustic soda and bleaching powder are made from common salt by a series of operations, but the electrical method does this neatly and cheaply in practically one operation; lime and carbon do not react by ordinary chemical processes, but in the electric furnace they react at once to form the valuable and familiar calcium carbide; carbon stays carbon except when the intense heat of the electric furnace converts it into artificial graphite. The list of such operations is a long one, and it may be said that the chemist has become a much more highly efficient and accomplished chemist since he became an electrochemist, and he is becoming more of an electrochemist daily.

Electrometallurgy applies electric energy to facilitating the solution of the problems confronting the metallurgist. Its birth is but recent, yet it has rendered invaluable service; it has made easy some of the most difficult extractions, has produced several of the metals at a small fraction of their former cost, and has put at our disposal in commercial quantities and at practicable prices metals which were formerly unknown or else mere chemical curiosities. It has, further, refined many metals to a degree of

purity not previously known. The metallurgist is rapidly appreciating the possibilities of electrometallurgical methods, and they already form a considerable proportion of present metallurgical practice.

Applied electrochemistry, covering in general all of the field just described, is therefore an important part of chemistry and metallurgy, and is rapidly increasing in importance. It is a new art, people are really only beginning to understand its principles and to appreciate its possibilities; it is an art pursued by the most energetic and enterprising chemists, with the assistance of the most skilled electricians. Some of its most prominent exponents are electrical engineers who have been attracted by the vast possibilities opened up by these applications of electricity. The chemists have worked with electricity like children with a new toy, or a boy with a new machine; they have had the novel experience of seeing what wonders their newly applied agency could accomplish, and it is no exaggeration to say that they have astonished the world—and themselves.

THE AGENTS OF ELECTROCHEMISTRY.

The operating agent in electrochemistry is, of course, electric energy, which may be used in three classes of apparatus, viz.:

(I) Electrolytic Apparatus.
(II) Electric Arcs and Discharges in Gases.
(III) Electric Furnaces.

I.

Electrolytic Apparatus and processes use or utilize the separating or decomposing power of the electric current. Whenever an electric current is sent through a liquid material which is compound in its nature, *i. e.*, a chemical compound, the current tends to decompose the compound into two constituents, appearing respectively at the two points of contact of the electric conducting circuit with the liquid in question, *i. e.*, at the surface or face of contact of the undecomposable conducting part of the circuit with the decomposable part. If the current has a definite direction the constituents appear at definite electrodes. The action is simply the result of the current extracting (or tending to extract) from

the electrolyte one of its constituents at each of the two electrode surfaces. All subsequent changes following upon this primary tendency of the current are called secondary reactions, and are practically simultaneous with the primary. These may even be regarded as truly primary reactions also, the primitive decomposing or separating power of the current passing being regarded only as a *tendency* or a *determining cause* which practically results in the reactions actually taking place.

This agency is an extremely vigorous and potent force for producing chemical transformations. It enables us, for instance, to split up some of the strongest chemical compounds into their elementary constituents, to convert cheap materials into much more valuable derivatives, to purify impure materials, in short, to perform easily some very difficult chemical operations and in some cases to perform chemical operations otherwise impossible. A description of all these various processes would take a volume, but a short explanation of a few of them will make the principles clear and suffice for my present purpose.

Electrolysis of Water: As a raw material, water may be said to cost nothing. Apply an electric current to it in the proper way, and it is resolved into its constituent gases, hydrogen and oxygen, as cleanly and perfectly as anyone could desire. These gases have many and various uses, and are valued each at several cents per pound. A whole industry has thus grown up, based on the simple electrolysis of water, to supply these two gases for various industrial uses. Europe possesses many of these plants; there are a few in the United States. The speaker has translated from the German a small treatise on this industry.

Electrolysis of Salt: Common salt, sodium chloride, is one of the cheapest of natural chemicals. It has some uses of its own, but centuries ago chemists and even alchemists devised chemical processes for transforming it into other sodium salts, such as caustic soda or soda lye for use in soap, soda ash or carbonate, for washing or glassmaking, and into chlorine bleaching materials. Chemical works operating these rather complicated chemical processes exist on an immense scale in all civilized countries; it is estimated that $50,000,000 is thus invested in Great Britain alone. The electrolytic alkali industry is barely twenty years old, yet it

is already more than holding its own with the older chemical process, and advancing rapidly; twenty years more will probably see the older processes entirely superceded—they are at present fighting for their existence. As for the electrolytic process, the salt is simply dissolved in water and by the action of the current converted into caustic soda at one electrode and chlorine gas at the other. By some special devices these are kept separate and collected by themselves, and the work is done. The principles involved are simplicity itself as compared with the older chemical processes, the only agent consumed is electric energy, and the products are clean and pure.

Chlorates: These are salts used on matches and in gunpowder. Chlorate of potassium is a valuable salt with important uses. It is made from common cheap potassium chloride, in solution in water, by simply electrolysing the solution without trying to separate the products forming at the electrodes. It is a simpler operation than the production of electrolytic alkali. Chlorate thus forms in the warm solution, and is obtained by letting the solution cool and the chlorate crystallize out. The ordinary chemical manufacture of this salt was tedious and dangerous; the electrolytic method has practically entirely superceded it.

Perchlorates: These salts have more limited uses, but are made by expensive chemical methods. The electrolysis of a chlorate solution at a low temperature, without separating the products formed at the two electrodes, results in the direct and easy production of perchlorates. I cite this more to illustrate what I might call the versatility of electrochemical methods, rather than because of its commercial importance.

Metallic Sodium: The caustic soda produced from salt can itself be electrolytically decomposed; this is the easiest way of producing metallic sodium. Sir Humphry Davy discovered sodium by electrolyzing melted caustic soda, and at this moment several large works are working his method on an immense scale. The caustic contains sodium, hydrogen, and oxygen, and the current simply liberates the sodium as a molten metal and frees the other two as gases, which escape into the air. The process is simplicity itself—when the exact conditions are known and rigidly adhered to. Metallic sodium is a very useful material to

the chemist, and the electrolytic method produces it at probably one-fourth the cost of making it in any purely chemical way.

Magnesium: This is a wonderfully light metal, whose chief use is in flash-light powders. Its compounds are abundant in nature, but its manufacture by any other than the electrolytic method is almost impracticable. The operation consists in simply passing the decomposing current through a fused magnesium salt—a chloride of magnesium and potassium found in abundance in Germany.

Aluminium: The most useful of the light metals; an element more abundant in nature than iron, yet which costs by chemical methods at least $1.00 per pound to produce; electrochemistry enables the makers to sell it at a profit at $0.25 per pound. This is probably the most useful metal given to the world by electrochemistry. Although the French chemist Deville obtained it by an electrolytic method in 1855, yet he had only the battery as a source of electric current, and the process was too costly. This very city of Pittsburgh was the real cradle of the electrolytic manufacture of aluminium, when, in 1889, Mr. Chas. M. Hall with the financial assistance of the Mellons and the business assistance of Captain A. E. Hunt, commenced to work his process up at 33rd Street on the "West Side." The principle of the process is here again one of beautiful simplicity—when it is once made known. Aluminium oxide, abundant in Nature, is infusible in ordinary furnaces, but easily melts and dissolves, like sugar in water, in certain very stable and liquid fused salts—double fluorides of aluminium and the alkali metals. On passing the electric current through this bath, the dissolved aluminium oxide is decomposed, appearing at the two electrodes as aluminium and oxygen respectively. When all the oxide is thus broken up, more is added, and the operation continues. One of the most difficult problems of ordinary chemistry is thus simply, neatly and effectively solved by electrochemistry. The lower cost of power at Niagara Falls drew the industry away from Pittsburgh, in 1893, and it is now run on an immense scale at several places where water power is cheap and abundant. Mechanical power is, however, being produced cheaper every year; gas engines have halved the cost of such power, steam turbines on exhaust

steam may even do better; there is no inherent impossibility in the return of the aluminium industry to the Pittsburgh district. Many other factors besides cost of power bear on the question; cost of labor, abundance of labor, cost of carbon, coal for heating, various supplies, railroad freights, nearness to the consumers, and many other considerations must be taken into account. Aluminium is certainly destined to become the most important metal next to iron and steel, and, as far as one can now foresee, will always be produced electrochemically. To have accomplished the establishment of this one single industry, would of itself have proved the usefulness of electrical methods and their importance to chemistry and metallurgy.

Refining of Metals: Unless metals are of high purity they are usually of very little usefulness. Electrolytic methods enable almost perfect purity to be easily attained, and in addition permit the separation at the same time of the valuable gold and silver contained in small amount in the baser metals. Over $100,000,000 worth of copper is electrically refined every year in the United States; the metal produced is purer than can be otherwise obtained, giving the electrical engineer the highest grade of conducting metal, while several million dollars' worth of gold and silver are recovered which would otherwise have to be allowed to remain in the copper. Again, the method is so simple that but a few words are necessary to set it forth in principle. The impure copper is used as one electrode—the anode—in a solution of copper sulphate containing some sulphuric acid; the receiving electrode—the cathode—is a thin sheet of pure copper, or of lead, greased. The electric action causes pure copper only to deposit upon the cathode, if a properly regulated current is used, while a corresponding amount of metal is dissolved from the anode. Silver, gold and platinum are undissolved, and remain as mud or sediment in the bottom of the bath; other impurities may go into the solution, but are not deposited on the cathode if the current is kept low. The cost of this operation is small, and the results are so highly satisfactory that 90 percent of all the copper produced is thus refined. Similar methods are in use for refining other metals, silver, gold and lead are thus refined on a large scale; antimony, bismuth, tin, platinum, zinc and even

iron can be thus refined; the field is very inviting to the experimenter and to the technologist, and is rapidly increasing in industrial importance.

Metal Plating: All electro-plating is done by the use of electrolytic methods similar to those just described. If we imagine the impure metal anode replaced by pure metal, and the receiving cathode to be the object to be electro-plated, we have before us the electro-plating bath ready for action. Everybody knows the value and use of gold, silver and nickel plating; less well known are platinum, cadmium, chromium, zinc, brass and bronze plating. These are among the oldest of the electrochemical industries. Electrotyping is only a variation of this work; also the electrolytic reproduction of medals, engravings, cuts, etc., and even the production of metallic articles of various and complicated forms, such as tubes, needles, mirrors, vases, statues, etc. The speaker has translated from the German a monograph concerning these last-named uses of the electric current. There is opportunity here to hardly more than catalogue these various branches of electro-metallurgical activity. Pittsburgh people will be interested, however, in knowing that many of the newer buildings in this city contain thousands of feet of electrical conduits zinc plated in splendid fashion by electrolysis, at a works within a few miles of this city. At McKeesport tubes are coated by dipping into melted zinc, on an immense scale, but the electrolytic method is gaining a foothold, and we may live to see all galvanizing in reality practised as it is spelled. The removing of metallic tin from waste tin scrap is also accomplished on a large scale by the application of similar principles. It is being operated at a distance from Pittsburgh, but your open-hearth furnaces use up annually thousands of tons of the scrap steel thus cleaned and saved for re-manufacture into useful shape.

Without having mentioned or described more than a fraction of the electrolytic methods in actual industrial use, I hope that I have made clear the importance and extent of this kind of electrochemical processes. Assuming this, we will pass to the consideration of another, entirely different and yet important, class of apparatus and processes.

II.

Electric Arcs and high-tension discharges through gases are capable of producing some chemical compositions and decompositions which are very useful, and profitable to operate. This is a branch of electrochemistry which has not been as thoroughly studied as some others, its phenomena are not as thoroughly under control as electrolysis and electro-thermal reactions, and its possibilities are not as thoroughly understood or utilized.

Ozone is being made from air by the silent discharge of high-tension electric current. The apparatus is so far simplified as to be made in small units suitable for household use, ready to attach to a low-tension alternating current supply. The uses for the ozone thus produced are particularly for purifying water and air; it makes very impure water perfectly safe to drink, and purifies the air of assembly halls and sick-rooms, acting as an antiseptic. According to all appearances, this electrochemical doubling up of oxygen into a more efficient oxidizing form is developing into a simple and highly efficient aid to healthy living.

Nitric acid is an expensive acid made from the natural alkaline nitrate salts, such as Chili saltpeter. These nitrates are the salvation of the agriculturist, for they furnish the ground with the necessary nitrogen which plants can assimilate. The Chili "nitrate kings" have gained many millions of dollars, even hundreds of millions, in thus supplying the world's demand for fertilizer. But, electrochemistry has another solution to this problem, which is rapidly rendering every country which adopts it independent of the foreign fertilizer. The air we breathe contains uncombined nitrogen and oxygen gases, which if combined and brought into contact with water furnish the exact constituents of nitric acid. The way to do this has been laboriously worked out, and the electric arc is the agent which does it. Air is simply blown into the electric arc, where it for an instant partakes of the enormous temperature, and on leaving the arc is cooled as quickly as possible. In the arc, the combination of nitrogen and oxygen is effected to a certain extent, and the mixture is cooled so suddenly that it does not find time to dis-unite. The nitrogen oxides thus obtained are drawn through water, and this solution of nitric

acid is run upon soda, to produce sodium nitrate, or on lime to produce calcium nitrate, the latter called Nitro-lime or "Norwegian saltpeter." These salts entirely replace the South American natural salt.

The materials used in this industry are air and lime, and to these is added electrical energy. Air is universal, lime cheap almost everywhere, and electrical energy is cheapest where water powers are most abundant. In Norway, water power can be developed and electrical energy supplied from it at a total cost of $4.00 to $8.00 per horse-power-year. Some other countries can do nearly as well. Under these conditions, almost every country can afford to make its own nitrates, and so be independent of other countries for the fertilizer needed in peace and the gunpowder used in war. Norway felicitates itself already on being thus independent; nearly 200,000 horse-power is being utilized there by a $15,000,000 syndicate, and the industry is spreading rapidly over Europe. The study of this problem, its solution, and the rapid development of this vigorous industry, is one of the most remarkable chapters in the history of recent industrial development. In this accomplishment, electrochemistry has signally aided the agriculturist, and demonstrably multiplied the food-supply resources of all civilized and highly-populated countries.

Boron is an element which has until recently defied the best efforts of chemists to isolate in a pure state. It is an element which may have important application in the manufacture of a high-class special steel—boron steel. Dr. Weintraub, one of our fellow members, has recently solved the problem of its production by an adaptation of the "oxygen-nitrogen" arc apparatus, and utilizing the same principle of introducing the material into the arc and very rapidly cooling the products obtained. We mention this not because of its great commercial importance at present, but because it shows how the "arc method" may be of wide application in solving other difficult chemical problems; it has opened before us a new method in chemical science, and may give birth to many and various new chemical industries.

III.

Electric furnaces are furnaces in which the necessary heat or degree of temperature is produced or attained by means of electrical energy. The electric current is used in these furnaces solely for its heating or thermal effect, and either alternating or direct current may be used, but alternating is preferred because of its easier generation and management, capability of being procured from transformers, and absence of electrolytic effects.

Electric furnaces render remarkable and highly valuable service to the chemist and metallurgist, for two distinct and unique capabilities; they can generate heat within themselves without the use of combustion and the consequent products of combustion to complicate the working of the furnace, and they can besides, if desirable, produce temperatures absolutely unapproachable in furnaces using fuel, and thereby enable the carrying out of operations only possible at these extremely high temperatures. The upper limit of electric furnace temperature is simply the volatilizing point of carbon, the temperature at which the material of which the lining of the furnace is made, is boiled away. This is about 3700° Centigrade or 6700° Fahrenheit. The simple statement that this is 3 times as high as the melting point of cast-iron, may give some notion of the enormous temperature here at one's command. Besides high temperature, the efficiency of application of electrical heat to the useful purpose is usually high, in many cases 50 to 75 percent of all the heat developed can be usefully applied, as against 5 to 50 percent utilized in fuel-fired furnaces. The heating value of thermal equivalent of the electric current is perfectly definitely known; one kilowatt-hour will furnish 860 calorics (3400 B. t. u.), which if applied usefully at 100 percent efficiency would bring to boiling and convert into steam 1.35 kilograms (3 pounds) of water, or bring to melting and melt about 3 kg. (7.5 lbs.) of cast-iron, or 2.5 kg. (5.5 lbs.) of steel.

Artificial graphite is a product particularly electrochemical in its manufacture. Your fellow-townsman, Dr. E. G. Acheson, has practically created this industry and his name sticks to the product—Acheson Graphite. No temperature but that of the electric furnace can convert the ordinary amorphous carbon, con-

taining small amounts of foreign substances, into pure, soft, homogeneous, unctuous graphite. The purity of the product and its quality has even surpassed the artifice of Mother Nature herself. Whereas before, graphite in small scales was laboriously gathered from Ceylon and Siberia, and with great pains worked up into graphite articles, now the articles are simply moulded in ordinary impure amorphous carbon, and converted through and through, retaining their shape, into finished and complete graphite articles. What this highly pure product is going to do for lubrication, for annihilating the friction of the world's machinery, perhaps only a few suspect and only Mr. Acheson knows. You will all know more about this soon, and everyone of you who uses machinery will profit by it. Meanwhile, in another direction, probably half the electrochemical industries now operating are beneficiaries of this invention, using artificial graphite anodes in electrolytic operations or as electrodes in electric furnaces. The electrochemical industry in general has been most wonderfully helped by this one electrochemical process.

Carborundum stands for a large industry, centered at Niagara Falls, and founded also by Mr. Acheson. Twenty years ago the name was not in the dictionary; now it is known all over the world as the most efficient abrasive material in use. First produced just across the Monongahela, in a little furnace as large as a cigar box, and sold for polishing diamonds at many dollars per ounce, it is now made by tons in electric furnaces of 2000 horse-power capacity, and competes successfully with such common natural abrasives as emery and common sand. And in fact, common silica sand, the most abundant material on earth, with common carbon, like coke, furnish all the ingredients necessary for the furnace to work upon to produce *SiC,* silicon carbide. Mr. Acheson not merely founded another new industry, but he discovered a new chemical compound; he has enriched science, promoted industry and created new instruments of service; no wonder that his scientific friends have showered on him honors,—the Rumford Medal, the Perkin Medal, and two years ago the presidency of this Electrochemical Society.

Silicon is the metal whose oxide is silica sand, and is by far

the most abundant metallic element on earth. Up until very recently it was to be seen only in chemical museums, costly and useless—a chemical curiosity. Now Mr. F. J. Tone, one of Mr. Acheson's former lieutenants, is producing it by the ton and selling it by the carload, at a few cents per pound. The chemical world has found uses for it, large uses, such as in solidifying steel, making good copper castings, reducing other metals from their oxides, chemical "pots and pans," etc. This illustrates again the variety of the achievements of electrochemistry. Here is a new material furnished the world at a low price and all sorts of workers are finding all sorts of advantageous uses for it. The electric furnace makes it from simply sand and carbon, with electric energy, and plus considerable "brains."

Calcium carbide is the product of another American invention. The name was scarcely in the chemical books, and the purveyors of the rarest chemicals did not have it on their lists, when Mr. Thomas Willson, trying to make something else in the electric furnace, made this compound from ordinary lime and carbon, and started an electrochemical industry which has spread all over the civilized world. I am almost tempted to say that there is a calcium carbide works everywhere but in Pittsburgh, but that would really be an exaggeration, and I will not say it. The best thing about calcium carbide is that it is easy to make; the raw materials may be found almost everywhere, and wherever power is cheap a flourishing calcium carbide industry may be built up. The curious thing about it is that its chief use is based on destroying it, acting upon it by water and forming acetylene gas. How great a boon acetylene gas has been to the bicyclist, automobilist, for lighting trains, isolated houses, stations and towns, needs no recital before this audience; but the value of acetylene as a means of welding with the blowpipe is only commencing to be appreciated. Acetylene welding is a convenience which owes its existence entirely to the electrochemical production of calcium carbide, and the iron and steel and other metal industries are being greatly helped by its use.

Titanium carbide is not as familiar as calcium carbide. It is made in a manner similar to the production of carborundum, using titanium oxide (rutile) and carbon. It has no uses similar

to calcium carbide, nor any like silicon carbide. But electrical engineers have discovered that as arc light tips or electrodes it gives the most efficient arc light yet discovered, with a light efficiency running up to 3 candle-power per watt of electrical energy. This is probably 50 percent of the theoretically possible conversion of electrical energy into light energy, and is doubly as efficient as has ever before been attained. What this means for street lighting everywhere is difficult to realize; perhaps the best and most easily understood comparison is to say that the titanium carbide arc lamp is to the ordinary arc, as the tungsten filament incandescent lamp is to the carbon filament lamp; you will all grasp the scope of that statement. With acetylene lighting on one hand, and titanium arc lighting on the other, we need say no more about the influence of electrochemistry on modern illumination.

Phosphorus. I stated before that the potassium chlorate on safety matches was all being made electrochemically. We can say practically the same of phosphorus. The electric furnace enables us to distill phosphorus much more easily and safely from the natural phosphates, than the older chemical methods. Calcium carbide gives us acetylene gas, and another electrochemical furnace gives us the phosphorus to "strike the light."

Ferro-alloys are alloys of iron with the more expensive metals, used in manufacturing steels of various kinds. Ferro-manganese is used in practically all steel, ferro-silicon is used in almost all. Ferro-chromium,—nickel,—tungsten,—molybdenum,—boron,—uranium,—vanadium are some of the alloys used to make the special alloy steels, such as find great use in rapid tool steel, automobile axles, armor-plate, gun-steel, etc. These alloys are of great importance to the steel industry, and are made almost exclusively in electric furnaces. The industry has flourished most in countries having cheap power, such as among the French Alps, and the importations into this country have been on a large scale. Fortunately, we are commencing at Niagara Falls, in Virginia and in Canada, to supply ourselves with these necessities of the steel industry, and we may look forward to a steady and large domestic development of this industry. Within a few miles of this hall, a small electric furnace is now at work making

ferro-tungsten to go into high class, expensive steel. Pittsburgh is going to take its share in the running of this particular electro-metallurgical industry.

Pig-iron would seem to be about the last item to find a place in an address upon the electrochemical industries. But the truth must "out":—electric furnace pig-iron is now being made, and made and sold at a profit. We will hasten to admit that the furnaces are small, that they are in California and Sweden, where fuel is expensive and power is cheap, that a great deal of money has been sunk in bringing them to their present condition; but after all has been admitted, the fact remains that electric furnace production of pig-iron is not a chimera, but an accomplished fact. Pittsburgh has been able to boast that she "could manufacture a ton of pig-iron and put it down anywhere in the world cheaper than it could be there produced." That may be *still* true *of the kind* of pig-iron which Pittsburgh is able to make, but there are grades and qualities of pig-iron (Swedish charcoal pig-iron, for instance) which are still imported into this country and sold at double the price of our domestic pig-iron. And, in the country where that charcoal pig is slowly, laboriously and skillfully made, the electric shaft furnace is able to compete with the charcoal blast furnace in producing this high quality pig-iron. Dr. Haanel, of the Canadian Department of Mines, has in a recent report given us the most reliable information about the running of this furnace. The construction is peculiar, and still somewhat experimental, the full power for which the furnace was designed has not yet been available for running it, the workmen are new to their tasks, the overseers are still learning, the irregularities in the running are not yet all overcome, and many of the minor details are yet being adjusted. The furnace is still, in brief, decidedly in the formative or experimental stage. Yet, notwithstanding, Professor Odelstjerna, one of the most expert of Swedish metallurgists, states that the cost of production is $1.50 per ton less than in the Swedish blast-furnaces. If that is true now, it needs little gift of prophecy to figure out at least $2.50 per ton saving when the furnace is properly run. Three similar furnaces of greater capacity, 2500 kilowatts each, are to be erected in Norway; three similar ones are to be put up at Sault Ste.

Marie, Canada. These are only the forerunners, we may be sure, of dozens or perhaps even hundreds which will be built and operated within the lifetime of most of this audience. The time at our disposal forbids me describing these interesting furnaces; I can only refer you to Dr. Haanel's interesting reports and to the transactions of this Society, particularly to our Volume XV. One surmise of my own I will, however, take time to mention: I have predicted that this electric furnace pig-iron, made without the admittance or use of air blast, will be far superior to ordinary pig-iron for conversion into steel, because of the absence of oxygen or, particularly, of nitrogen. *Time* will test this prediction, too.

Electric Steel is at present a topic of absorbing interest and great potentialities. It was primarily a competitor of the most expensive kind of steel—crucible steel. It was first made commercially in 1900, by Mr. F. A. Kjellin of Sweden, by melting together in an electric furnace the same high grade materials which are usually melted down in crucibles to form crucible steel. The product was made equal in quality to crucible steel, it was produced in lots of a ton or more at a melt, of very satisfactory uniformity, and with cheap water power to furnish electricity the cost was considerably below that of crucible steel.

The steel melting pot or crucible is a siliceous vessel, holding about 100 pounds of steel, lasting only a few heats, and lifted in and out of the furnace by manual labor. The consumption of fuel to get the required melting heat is wickedly wasteful; not over five percent of the heat-developing power of the fuel used is efficiently utilized as heat in the melted steel, and the actual proportion is usually less than half that much. The cost of labor, crucibles and fuel is excessive, and to this must be added the high cost of the pure material which must be used—practically the purest iron which can be made.

The electric furnace is changing all this, rapidly in continental Europe, slower in Sheffield, and still slower in America; but the change is spreading surely and inevitably. Real crucible steel will soon be a thing of the past, supplanted entirely by electric furnace steel of equal quality, made and sold much more cheaply.

The electric furnaces used are of almost all types. The induc-

tion furnace was developed commercially by Kjellin in Sweden, improved, enlarged and greatly developed by his associates in Germany, combined with the Colby pattern in America, and still further modified by Hiorth in Norway. Thirty-six of these furnaces, the maximum capacity being one at Krupp's works at Essen, 8½ tons at a charge, are now built or building. The American Electric Furnace Co. is organized to push their building and operation in America. The arc radiation furnace was developed by Major Stassano, an Italian artillery officer. It melts by heat radiated from powerful electric arcs. Several of these are in operation in Europe, and a gentleman managing one of the large American steel companies, who has just returned from an inspection of the different electric steel furnaces operating in Europe, tells me that he considered the Stassano furnace as doing the best work, all around, of all the furnaces he saw in operation. I have seen this furnace operating smoothly and regularly, in Turin, producing steel for castings which were being sold in competition with open-hearth and bessemer steel castings in the open market. The single arc furnace is best illustrated by the Girod furnace, which is built like the body of an open-hearth furnace with the electric current entering the bath by carbon electrodes suspended above it, and springing arcs to it, while the current leaves the bath through metallic conductors passing through the saucer-shaped hearth below the level of the metallic surface. These furnaces work with great regularity, and a large number are operating in Europe, in capacities up to 12 tons each. I am informed that the Krupp Works at Essen has just contracted to put in five of these of the 12-ton size, which would confirm statements made to me by my European friends that this furnace is working the best of all the electric steel furnaces now operating in Europe. The double arc furnace, of which the Heroult furnace is the most familiar type, works with two arcs in series, the current entering the bath and leaving it also through electrodes suspended above it. The general style is that of an open-hearth furnace with electrodes passing through the roof. The current used is roughly 100 kilowatts per ton of steel capacity, and the largest so far operated is 15 tons. A three ton furnace of this type was seen by you at the Firth-Stirling Steel Works at Demmler, yesterday, producing crucible-quality steel.

The U. S. Steel Corporation has acquired licenses to operate the Heroult furnace, and has already two 15-ton furnaces in operation. Without doubt, the Heroult furnace is at the present time the most popular and successful electric steel furnace in the United States. I have not time to more than name the Keller, the Hiorth, the Harmet, the Frick—all of which are operating at this present moment, in Europe.

There are other ways of making steel than the crucible method. Bessemer steel is the cheapest, and open-hearth steel is next best. These two varieties grade into each other in quality, but between open-hearth and crucible steel there is an enormous gap in price and in quality which is destined to be bridged over by intermediate qualities of electric steel, as it becomes cheaper and is manufactured on a larger scale. This will soon become one of the large uses of the electric method, occupying a field peculiarly its own. It will enable steel manufacturers to supply steel better than the best open-hearth product at less than the price of crucible steel. I need not enlarge upon the advantages of this, to a Pittsburgh audience.

There are also varieties of methods of manufacture of steel, aside from the melting together of highly pure materials as in the crucible method, which are equally available in most types of the electric furnace. The Bessemer converter takes liquid pig-iron as it comes from the blast-furnace and by rapid oxidation by air blast converts it into steel. Mr. Heroult has tried to combine the Bessemer converter with the electric furnace, in one apparatus, the idea being to first oxidize the metal by air blast and then to finish it while electric current supplied the necessary heat. I have no information that this combination furnace is anywhere in successful operation, but the equivalent of the same operation performed first in the Bessemer converter and then on the blown metal transferred into an electric furnace for finishing, is already in regular commercial operation at the South Chicago Works of the U. S. Steel Corporation. I have had the privilege and pleasure, thanks to Mr. Heroult, of studying that operation, in company with Mr. Heroult and the editor of *Metallurgical and Chemical Engineering*. You may find a description of the process in the April number of that journal. so I will not repeat it here—except so far as to say that 15 tons

of the product of the Bessemer blow, oxidized to the extent usual in the Bessemer converter, was kept melted less than two hours on the basic hearth of the electric furnace, treated with two different slags to refine it from fosforus and sulfur, de-oxidized or "dead-melted," and then poured into ingots of steel intended for axles. The steel produced was of better quality than the usual corresponding open-hearth metal, and was produced at slightly *less* total cost. This combination process bids fair to give a new lease of life to the declining Bessemer steel industry; its economic importance will appeal particularly to this audience.

The open-hearth steel furnace is, at present, the most important of the methods of manufacturing steel—"tonnage steel." It makes steel from pig-iron and scrap of proper quality, or from pig-iron and iron ore (mill-scale), or from pig, scrap and ore. It makes its best steel on silica hearths from high grade material low in sulfur and fosforus, and its cheapest steel on basic hearths from almost anything. The electric furnace can do any or all of these things, and, as a general proposition, produce better steel from given materials than the open-hearth furnace. Under what circumstances it will pay to use the electric furnace instead of the open-hearth furnace would take at least one lecture to discuss; we will not go deeply into it here. In Europe, countries which have very cheap water power, around $10 per horse-power year, and fuel costing $4 to $6 per ton, are finding the electric furnace the cheaper; with power costing $20 and coal $5. the two are about on equal terms; in Pittsburgh, with power at $30 and coal at $1.00, the open-hearth furnace is by far the cheaper, for producing such steel as it can produce. However, even here, the combination of Bessemer and electric furnace is possibly cheaper than the all open-hearth process; the combination of open-hearth and electric furnace processes is quite possible and practicable, to produce crucible-quality steel on a large (tonnage) scale, and the combination of the open-hearth and electric furnace into one furnace is not only a possible combination, but is actually being "tried out." The latter idea is to take an open-hearth furnace, and to place electrodes in the roof. The furnace is run as an ordinary open-hearth furnace, with the electrodes withdrawn; and at the close of the open-hearth heat

gas and air are shut off entirely, the electrodes lowered into proximity to the bath, and the heat finished as an electric furnace heat. The idea is sound and practicable, and will result in the production of better steel than can be obtained from any open-hearth furnace, at but a slight advance on the cost of the open-hearth steel, say $2.00 to $3.00 per ton.

As to the capacity for enlargement of electric steel furnaces, they started out to duplicate the crucible steel process, producing 100 pounds of melted steel at a heat, and in eight years have risen to 15 tons' capacity. In Europe, an electric calcium carbide furnace of 18,000 kilowatts, capable of producing 200 tons of carbide daily, is in practical operation. A furnace of like power capacity could be built to make steel, and would be a 200-ton steel furnace, or larger. We can therefore say with assurance, that with a little more experience and experiment, electrometallurgists will be able to furnish the steel maker with electric steel furnaces as large as are wanted—up to 200 tons' capacity if desired.

The electric manufacture of steel is coming upon you in Pittsburgh, surely and quickly. It will be an immense industry, and will bring with it corresponding power and wealth. It will call for the best efforts of your mechanical engineers, metallurgists and electrical engineers, aided by electrometallurgists whom you must either bring in or develop yourselves.

The year 1910 will be historic in your annals, because of the great awakening to your advantages as an electrochemical center and from the fact that future historians will record: "In that year the electric manufacture of steel was first begun in the Pittsburgh District on a commercial scale."

People of Pittsburgh! Your city and district are destined to play a large part in this grand electrochemical and electrometallurgical development of the future. The electrochemical fraternity of America have knocked at your doors, you have received them with warmest cordiality, listened to them with keen attention, and they will repay a hundred fold your enlightened self-interest.

You will take their words to heart, you will act upon them with your wonderful industrial aggressiveness, and the future possibilities of electrochemistry will be *yours!*

A paper read at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 5, 1910, President L. H. Baekeland in the Chair.

POSSIBILITIES OF CHEAP POWER IN THE PITTSBURGH DISTRICT.

By F. Crabtree.

The price of fuel usually having so much to do with the cost of power, one would naturally assume that the Pittsburgh district would offer exceptional opportunities for the development of electricity at a low cost. With natural gas at from 12 to 16 cents per thousand cubic feet, coal at one dollar per ton or less, and waste energy waiting to be utilized, it would seem as if few districts in the United States offered greater possibilities in the way of cheap power. And I might make my remarks very brief by saying that we may get the possible cost of current here from the cost of generating current at any other Eastern city with similar conditions as to labor, by either eliminating entirely the fuel cost, or bringing it down to less than 0.14 cents per kilowatt hour. But it may seem worth while to elaborate a little on this simple statement.

In speaking of the Pittsburgh district, we should include the larger part of Western Pennsylvania, where the coal and iron industries are centered. The city of Pittsburgh has long been too small to hold them within her corporate limits, and they have spread up and down the rivers, over several hundred square miles; but their interests are so intimately bound up in those of the city itself that the whole region is really "Greater Pittsburgh."

The trend of all good business nowadays is to avoid waste, to cut down unnecessary losses; so the natural tendency is to turn to the long recognized waste in both coke making and blast furnace smelting as possible sources of cheap current; and at first glance the field looks very inviting.

Power From Coke-Oven Gases.

It has been demonstrated by actual experience, under every-day working conditions, that from each bee-hive coke oven in

regular operation enough hot gases escape to generate from 15 to 20 boiler-horse-power. Usually there are more than 30,000 coke ovens in operation in Western Pennsylvania, so that apparently there is a waste of at least 450,000 horse power. A very simple change in construction will allow the installation of boilers to convert this waste heat into steam; flues must be installed connecting with each oven and with a stack, and boilers placed so that the hot gases must pass through them to reach the stack. The construction of the flue and stack would add about $150 to the cost of each oven. Steam turbines, boilers and accessories would bring the cost of installation for a plant of 3,000 or 4,000 kw. to $80-$100 per kilowatt capacity. At such a plant, there being no coal or ashes to handle, the labor cost would be low and the fuel cost would be eliminated under ordinary conditions. Therefore the fixed charges—interest on sinking fund, taxes and insurance—would constitute the larger part—at least 75 percent—of the cost of generating the current.

In estimating the actual cost in dollars and cents of generating current, so many variables must be considered, and so many terms used that are indefinite in their meaning, that it is difficult to avoid conveying a wrong impression or making assumptions that are not acceptable to one's hearers. One man considers 12 percent a reasonable figure for fixed charges, another man thinks 15 percent not enough. One man calls 8,760 kw. hours a kilowatt year; another man prefers 7,200 kw. hours; still another wants 6,600. One man may consider the full capacity of his generator as 100 percent load factor, another calls it 100 percent equipment factor. One man calls the power required at the highest peak of the load his 100 percent load factor. Good engineering would in most cases require the generators to be in such units that a spare generator can be carried without too large an increase in investment. If there are three 2,000 kw. units, two for regular use, and the third for a spare in case of breakdown, a difference may arise in rating the capacity of the plant. In the following estimates I shall consider the full capacity of the regularly operated machines for 8,760 hours per year as the 100 percent load factor. Of course, this is a condition never obtained in actual practice; but as many electrolytic industries should operate continuously, it may serve as reasonably as any other assump-

tion. I shall also assume 12 percent of total investment as covering the fixed charges, unless otherwise specified.

Under these conditions, then, the cost of current at a 3,000 to 4,000 kw. plant would approximate as follows, being expressed in cents per kilowatt hour:

Load Factor	100 Percent	50 Percent	33 Percent	25 Percent
Fixed charges.....	0.18 to 0.20	0.36 to 0.40	0.54 to 0.60	0.72 to 0.80
Labor, supplies, and maintenance	0.07 to 0.07	0.10 to 0.10	0.15 to 0.15	0.20 to 0.20
	0.25 to 0.27	0.46 to 0.50	0.69 to 0.75	0.92 to 1.0

A quite common unit for a coke-oven plant is 200 ovens, which would furnish the heat for such a plant.

Power from Blast-Furnace Gases.

The possibilities in the way of power generation from blast furnace gases have been so often and so fully discussed that only a brief resumé is desirable here. It has been shown that for each ton of pig-iron made in a coke blast furnace under our conditions there is produced 150,000 to 160,000 cu. ft. (4,300-4,600 cub. meters) of gas, having a heat value of 90-100 B. T. U. per cub. ft (800-890 Cal. per cub. meter). From one-fourth to one-third of this gas is required for heating the air going into the furnace, leaving the balance of 100,000 to 120,000 cub. ft. available for power purposes. It requires 130 to 150 cub. ft (3.7 to 4.3 cub. meters) of this gas, burned in a gas engine, to generate one kilowatt hour; therefore, it is possible to get 600 to 800 kw. hours for each ton of pig-iron made, or for a furnace making 450 tons of pig-iron per day, there could be generated 270,000 to 340,000 kw. hours. Expressed in another way, we may say that the power possible is 10,000 to 14,000 kw. One-fourth of this will suffice to operate all the machinery of the plant, leaving 8,000 kw. or more available for outside use.

The cost of installing a gas engine-electric generating plant would be $100 to $110 per kilowatt capacity; the labor expense in operating would be smaller than in the case of the coke-oven plant previously considered; but the maintenance and repair charges would be higher. The net result would be about the same cost for power in both cases—that is, with a 50 percent load factor, current would cost not far from 0.5 cent per kilowatt hour.

If we consider the number of blast furnaces in Western Pennsylvania, and the great tonnage of pig-iron produced, the above figures would indicate enormous possibilities in the way of power development. As a matter of fact, irregularities in operation would materially decrease the amount of power that could be relied upon as being always available; yet there would still be an available amount of power that it is a technical as well as commercial sin to so largely waste. Where blast furnaces are connected with steel works, it is, of course, the custom to use the gas more or less by converting it into steam for use in mill engines. At a few plants, gas engines have been installed to utilize a portion of the gas, both for operating blowing engines and for generating electric current; but these have, with one exception, been for only a portion of the gas available.

Two or three causes have delayed the complete adoption of the gas engine-electric equipment; one has been the belief, more or less justified for a while, that the gas engine was in an early stage of development, and that improvements were being made so rapidly that it seemed wiser to wait a few years and get a more nearly perfected engine; again, for a time there was the fear that the gas engine might not be absolutely reliable—that "breakdowns" might interfere with the operation of plants; and thirdly, a very serious cause is the expense of equipment. According to the preceding calculation, the expense of installing a gas-engine generating plant capable of utilizing the gas of a modern 450-500-ton furnace would be well above $1,000,000. To justify the expense there must be the assurance of a reliable market for the current at a good load factor, and of better profits than can be obtained by investing the money in some other way.

Recently there has been a feeling that a less complete utilization—but at a much smaller expense—is a wiser policy. At an existing plant, already equipped with boilers and steam engines, it is possible to install low-pressure turbines and condensers, largely increase the power development and make a much larger profit on the investment. Consider a blast furnace, not connected with a steel works, that is now simply furnishing its own power by burning the gas under boilers. For about $50 per kilowatt capacity, steam turbines can be installed that will yield a surplus power of 2,000 to 3,000 kw. On this basis the fixed charges

(which in the cases previously considered amounted to about 80 percent of the cost of current) would amount to not more than 0.11 cent per kilowatt at 100 percent load factor, or 0.22 cent at a 50 percent load factor. Also, in such a plant operating and maintenance charges are low, so that the extra current generated can be obtained very cheaply, say at 0.2-0.4 cent per kilowatt hour.

Power From Natural Gas.

But suppose we consider the possibilities aside from these waste energy plants. The Pittsburgh district has two cheap fuels, natural gas and coal. The former is excellently adapted to use in gas engines, and will produce 1 kw. hour on 11 to 15 cub. ft. (0.32 to 0.43 cub. meter) of gas. At 15 cents per thousand cub. ft. (28.6 cub. meters), this is equivalent to a fuel cost of 0.16 to 0.23 cents per kilowatt hour.

This, it must be remembered, is without any gas making or purifying apparatus. An engine running on natural gas requires very little labor; there are no ashes or dirt to take care of; so that if the supply of gas is reliable and at a price approaching the above, electric power can be generated at a very reasonable cost, according to the size of the plant. A moderate-sized plant should not cost more than $125 per kilowatt capacity at the most, and large plants, $100 per kilowatt, or a little less. Labor and repairs should be low, as in the case of the blast furnace engine, and it should be reasonably safe to estimate the cost of power delivered at the switchboard as the same as in the case of blast furnace gas engines—0.20 cents per kilowatt hour for fuel. That is:

Load Factor	Full Load	50 Percent	33⅓ Percent	25 Percent
Fixed charges	0.20 cent	0.40 cent	0.50 cent	0.80 cent
Labor and supplies	0.05 "	0.10 "	0.15 "	0.20 "
Fuel	0.20 "	0.20 "	0.20 "	0.20 "
	0.45 "	0.70 "	0.85 "	1.20 "

Power From Producer Gas.

If we consider producer gas we have some definite data concerning moderate-sized plants in recent transactions of the American Institute of Electrical Engineers. Mr. J. R. Bibbins

gives data for a 700-kw. plant, erected at an expense of $96,000, and furnishing electricity at the following costs:

Load	Price of Coal	
	$1.00 Per Ton	$2.00 Per Ton
5,040,000 kw. hrs. per year.....	0.25 ct. per kw. hr.	0.601 ct. per kw. hr.
2,520,000 " " " "	0.978 " " " "	1.086 " " " "

As coal can be obtained in Pittsburgh for $1.00 per ton, or less, the above figures may be considered applicable. Mr. E. D. Latta, of Charlotte, N. C., reports the operating cost of current at a moderate-sized producer gas plant, using coal at about $4.00 per ton, as 0.885 cent per kilowatt hour. If the coal were to cost $1.00, as at Pittsburgh, then the operating cost would be 0.624 cent per kilowatt hour, on output of 3,355,907 kw. hours per year (about 36 percent of the full load capacity, full year's time). Fixed charges would bring this to about 1 cent per kilowatt hour.

Figures given for a producer-gas plant of 3,000 kw. capacity, operating on coal at $2.75 per ton, at an ordinary commercial load, show cost of current to be below 0.8 cent per kilowatt hour; with coal at Pittsburgh prices, the cost would be less than 0.7 cent per kilowatt hour.

It is generally considered that for large plants, using coal as fuel, the steam turbine equipment gives the most economical results. A new plant, erected and completely equipped, will cost not far from $80 per kilowatt capacity, as previously estimated in considering the utilization of waste heat from coke ovens; and the cost of current would be about the same as in that case, with 0.13 cent per kilowatt hour added for cost of fuel.

As partially confirming the foregoing estimate, the following statements may be appropriate. We are told that the Illinois Steel Co. charges its electric steel furnace at South Chicago 0.5 cent per kilowatt hour. A steam plant, located close to coal mines and furnishing current for lighting and traction, reports operating costs, including fuel, labor, supplies and maintenance, at less than 0.4 cent per kilowatt hour; another and much larger plant, using steam turbines in part, estimates labor, supplies and ordinary maintenance at less than 0.07 cent per kilowatt hour.

Conclusions.

The estimates given are necessarily somewhat indefinite; it was the intention to have them a little high, rather than low; and if accurate, they show that current can be generated at from 0.5 cent to 1.25 cents per kilowatt hour, according to the size of the plant and the load factor. Few sections of the country depending on coal or other fuel can show as low costs, and few hydro-electric plants can do appreciably better. A recent discussion in the Transactions of the American Institute of Electrical Engineers shows the average investment in seven hydro-electric plants to be $140 per kilowatt capacity. As this is 40 percent greater than the investment expense in some of the foregoing estimates, it follows that if the same rate were allowed for fixed charges—and in several cases the fixed charges amounted to 70 percent or 80 percent of the total cost—then these plants cannot generate electric current at a lower cost than can plants in the Pittsburgh district.

It is to be remembered, of course, that these estimates all refer to the costs of current delivered at the switchboard of the generating plant. If the current is used close to the switchboard, the cost of delivery will be low; if it is to be used at a considerable distance, the cost of power delivered will be materially increased by interest and maintenance charges on the transmission equipment, by transformer losses, etc., as well as by overhead charges in case of commercial power plants. These items vary enormously with conditions, such as distance, climate or weather, amount of power used, regularity of load, etc.; so that the cost of power bears no close relation to the cost of generation, except under specified conditions.

Carnegie Technical Schools,
May 5, 1910.

DISCUSSION.

CHAIRMAN BAEKELAND: I would like to add a few remarks relative to a very important factor which is often overlooked

when we are discussing power for electrochemical industries. In a good many instances where an electrochemical industry requires a large amount of power, it also requires a considerable amount of coal; and some of these industries, for instance, the electrical manufacture of caustic soda and bleach, require such an enormous amount of coal that this factor itself might become a decisive factor for making it desirable to locate an industry of that kind right in a center where power is cheap and coal is cheap, as in Pittsburgh. It is a matter very often overlooked. Electrochemists speak of power, but they forget that they often spend about as much money for coal as for power.

A paper presented at the Seventeenth General Meeting of the American Electrochemical Society, at Pittsburgh, Pa., May 5-7, 1910.

INDUCTION FURNACE PROGRESS.

By T. Rowlands.

So much has been written on the induction furnace that it appears somewhat difficult to approach the subject without repeating numerous statements and facts. As this is the case, I must ask your indulgence, as I will be compelled to once more call your attention to certain particulars, but I hope to bring fresh points to your notice.

The history of the induction principle is now so well known that it is unnecessary to more than point out that the first commercial furnace was put into operation in 1902, at Gysinge, Sweden. During the past eight years great progress has been made, and now it is quite recognized that the application of the principle has been established beyond all doubt, as furnaces of comparatively high tonnage are in active operation. At the present moment 16 tons capacity per charge is regarded as the maximum, although there seems no doubt that furnaces of greater capacity can and will be designed as necessity demands.

THE SIMPLE INDUCTION FURNACE.

These are of the Kjellin-Colby design and intended for melting purposes only, as the bath forms an annular channel in a crucible of suitable refractory material, and the crucible is so designed to allow the centre leg of the transformer, together with the primary coil, to pass through it. This is clearly shown in Fig. 1.

These furnaces are built to take charges from 10 pounds to about 3 tons. The construction of furnaces of greater capacity has been developed into the combined or Rochling-Rodenhauser type.

Uses of Simple Type.

This type of furnace is now running in competition with the crucible process for the manufacture of steel. Where power is

moderately cheap, the cost of melting is very low as compared with the crucible process. It is only necessary to but casually look into the question and this point will be brought home with great force.

The best practice in the old coke method of melting, as followed in Sheffield, shows that fuel and crucibles alone cost about $14 per ton, and, in this country, using plumbago crucibles and working with gas producers, the cost is from $10 to $11 per ton.

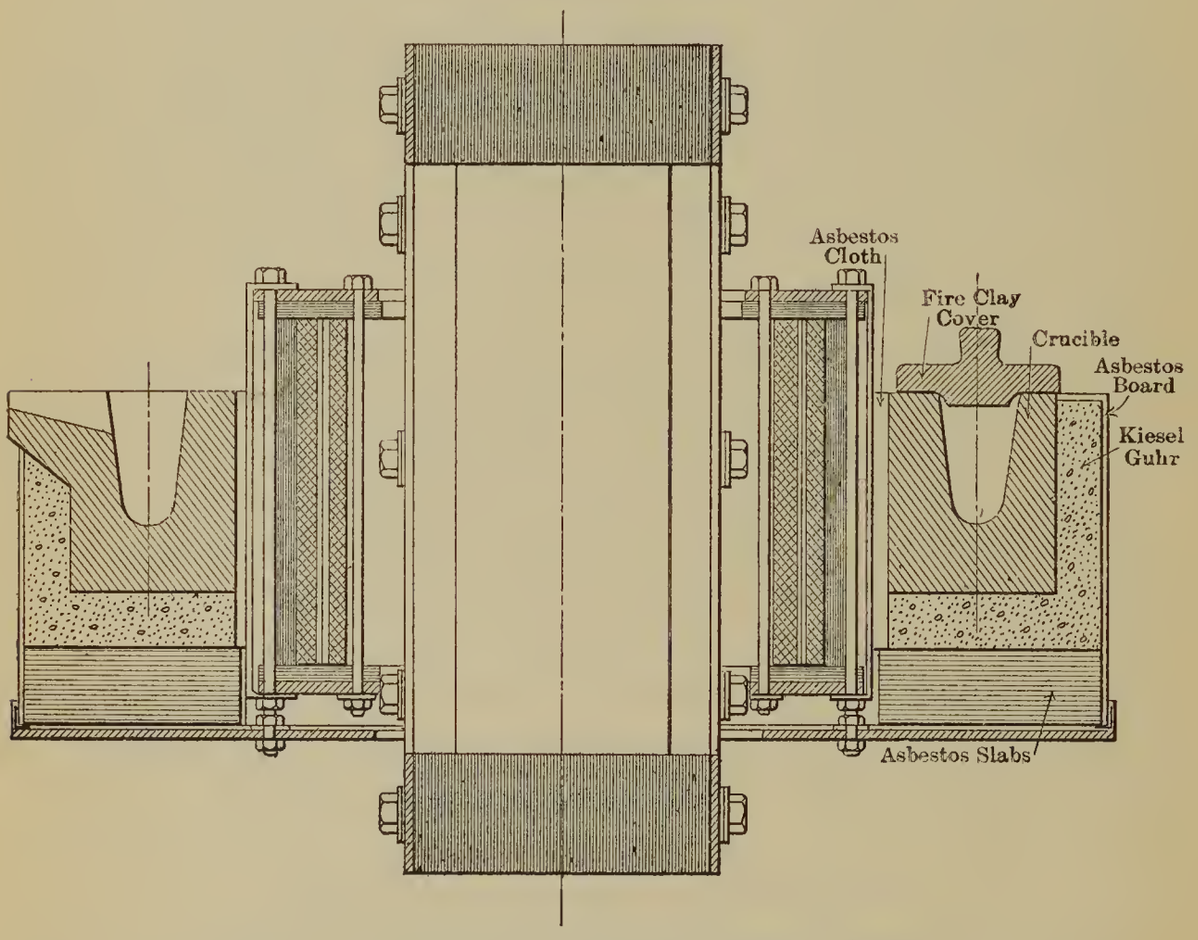


FIG. 1. Simple design, Kjellin Induction Furnace. (From Laboratory Type).

If a medium-sized induction furnace, capable of melting about 4 tons per 24 hours, pouring only 1,000 pounds per cast and working on a high power consumption, is taken for comparison, and we allow a high cost for furnace lining, as follows:

750 kw. hours per gross ton at 0.5 cents per kw. hour.....	$3.75
Lining per ton	1.00
	$4.75

it will be seen that the saving effected on melting, for fuel and crucibles only, amounts to from $5 to $10 per ton.

The economy is even much greater, for, in the comparison, the power was taken at 0.5 cents, which is a high cost, and the consumption of 750 kw. hours is also very high; for, as will be seen later, when melting regularly, the consumption for tool

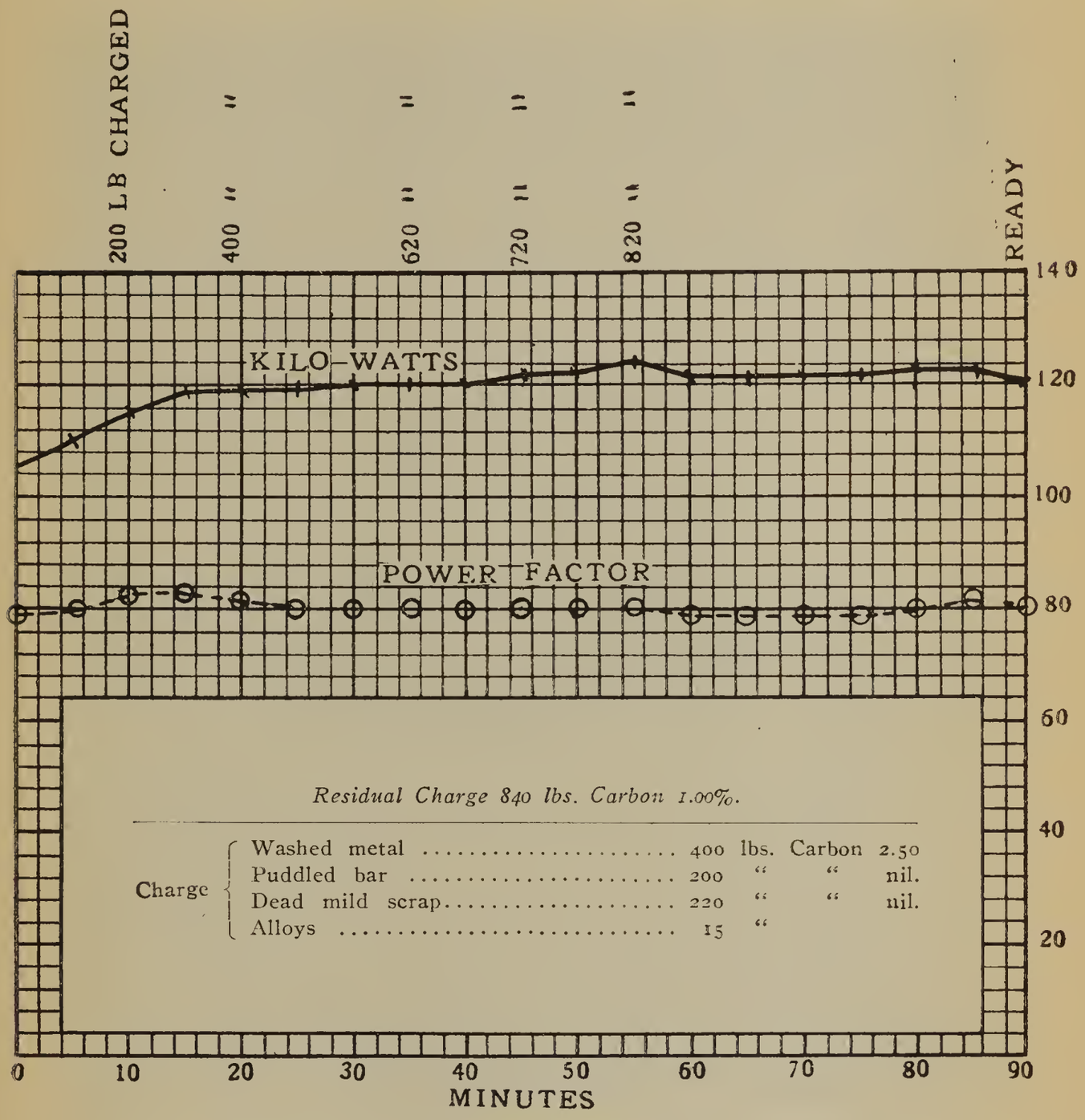


FIG. 2. Power Consumption and Power Factor; Charge 800 lbs. (364 kg.).

steels is much lower, but a high figure is given in order to allow for adjustment of compositions on making alloy steel, and also to allow for melting medium and low carbon steels. Then, again, the labor question has not been considered. Excluding the labor for the casting-pit, which is about the same in electric and crucible

processes, the electric furnace hands are fewer, and it is quite the regular thing for one man and a boy to do all the work on a furnace tapping one ton each heat. The actual saving will be between $7 and $13 per ton of ingots.

The regularity of the composition of the steel is another factor in favor of electric melting. Any irregularity in the composition of the steel can be adjusted directly in the furnace before tapping. This, of course, cannot be so finely regulated in crucible practice. Bearing on this point, it would be as well to state the evidence given the writer by a friend, who has been operating in his department a furnace tapping about 3,000 pounds per heat. He stated that the only charge he found it necessary to correct was

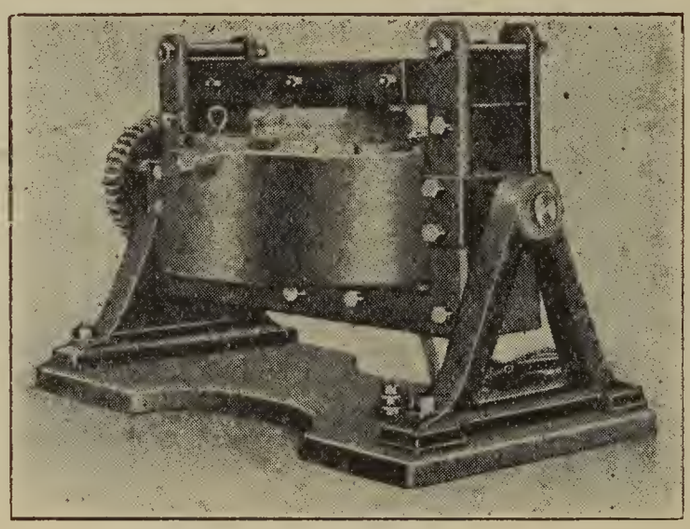


FIG. 3. 10 Kw. Furnace, National Physical Laboratory, Teddington, England. Supplied by Grondal-Kjellin Co., London, England.

the first one, as all the following charges were remarkably regular—always within a very narrow margin of the predetermined carbon percentage. High-speed and other alloy steels are just as regular, and the loss is very much less than in the ordinary method.

When operating a 150-kw. furnace at Niagara Falls, remarkable results were obtained. Several times the charge was ready within 1¾ hours from commencement of charging, and, on more than one occasion, in 1½ hours. Only on special occasions was the furnace pushed, for, as it was erected for demonstration purposes, the product was not marketed, but anyone who wished could have what steel he desired.

On one of these special occasions, a heat of over 1,000 pounds

of 1.2 per cent. carbon steel was charged and poured just under 1½ hours, the power consumption being only 440 kw. hours per ton. This result is exceptionally good, but, with suitable arrangements for handling the product, there is no reason why

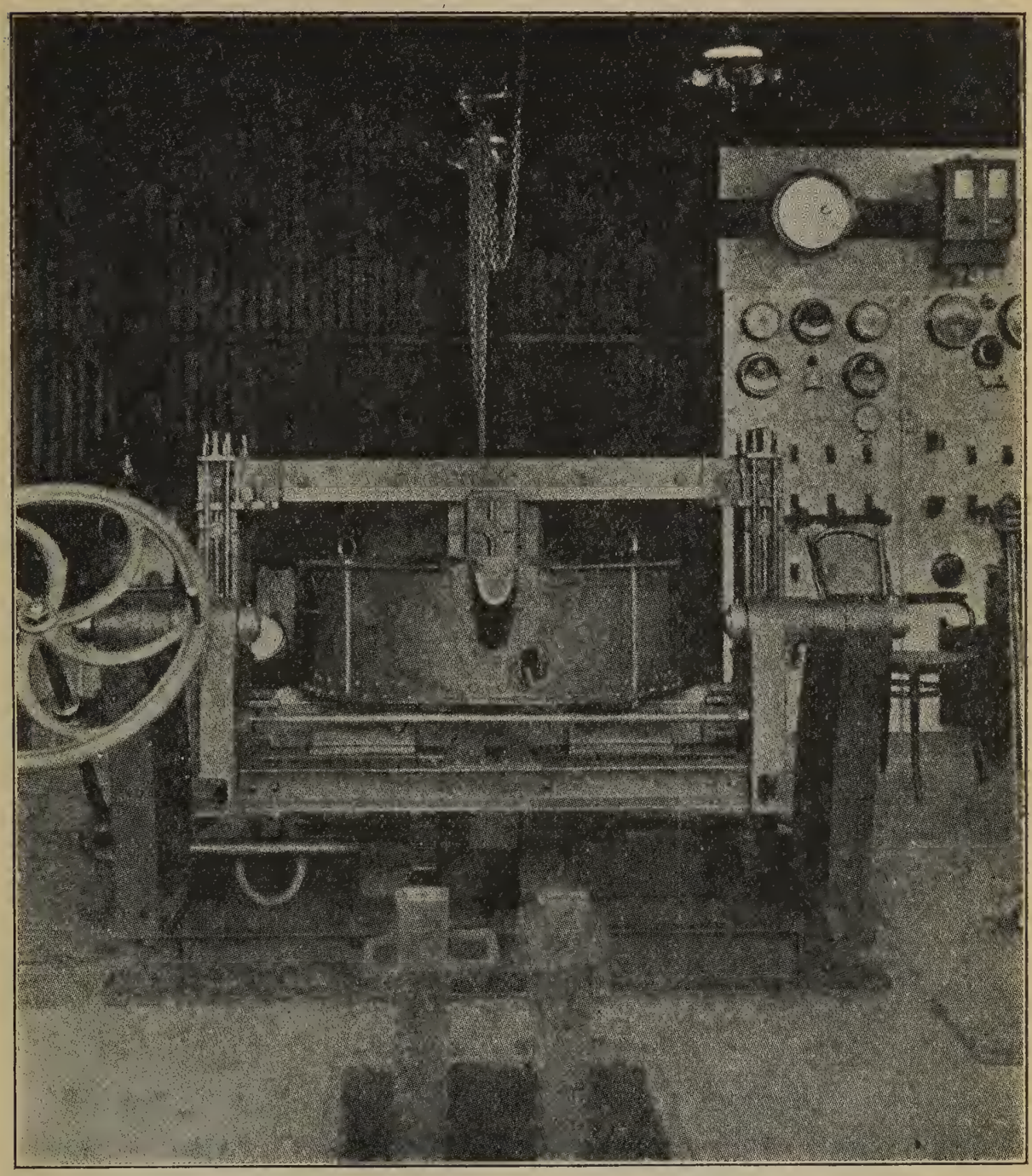


Fig. 4. 60 Kw. Furnace, Erected for Sheffield University.

carbon tool steel should not be regularly produced with a consumption of under 600 kw. hours per ton.

Fig. 2 illustrates the power consumption and power factor on a charge of over 800 pounds:

Before leaving the subject of crucible quality steel, it might

be well to call attention to the consideration this particular type of furnace is receiving in Sheffield.

The first firm to take up the matter was Vickers' Sons & Maxim,

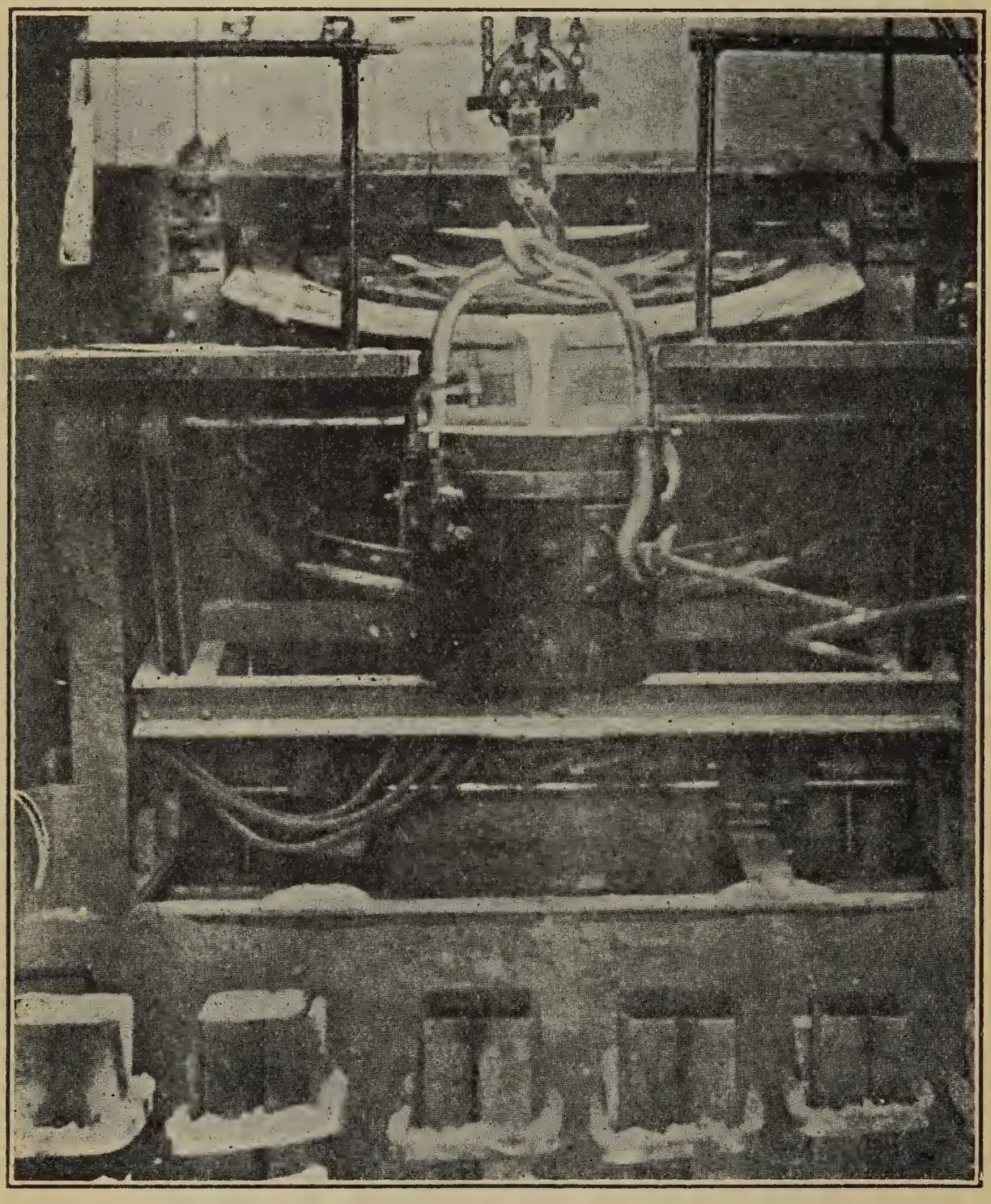


Fig. 5. 100-150 Kw. Kjellin Furnace; Niagara Falls.

Ltd., who erected a furnace of 250 kw. capacity, which, after preliminary trials, commenced active operations in the spring of 1908.

About this time a committee of manufacturers was formed to

go very thoroughly into the quality and costs of production of high-grade steel by electricity. A technical sub-committee visited electric furnace plants, the Kjellin furnace at Gysinge, Sweden, attracting a lot of attention. They were very well satisfied with the material produced, and, as a direct result of their exhaustive tests and report, a furnace of 300 pounds' capacity has recently been put in operation in the metallurgical department of the Sheffield University.

Another of the large firms, always in the forefront on improvements, is William Jessop & Sons. They hope to immediately commence operations on a furnace capable of producing 8 to 10 tons per day. In fact, this may already have started. It was only after long consideration and investigation as to the best furnace for their purpose that their decision fell on the Kjellin furnace. They had already tried out one of another design.

It will be perfectly apparent that this class of melting is making headway in the most conservative of all steel centres, Sheffield.

Fig. 3 shows a 10-kw. furnace erected at the National Physical Laboratory, Teddington, England, by the Grondal-Kjellin Co., London.

Fig. 4 illustrates a 60-kw. furnace, such as was erected at the Sheffield University by the Grondal-Kjellin Co.

Fig. 5 shows a furnace erected at Niagara Falls, N. Y., by the American Electric Furnace Co., 45 Wall Street, New York.

Leaving the subject of steel melting for a short time, the melting of other metals will be touched upon.

NICKEL MELTING.

Experiments were carried out at Niagara Falls, working with a 60-kw. furnace. The furnace lining was of magnesite, thoroughly baked in, and heated to redness by means of an iron ring. This ring was removed, molten nickel poured in, the current switched on and heating of charge commenced. The molten

nickel charge was 108 pounds, and the charging of cold nickel commenced at 2.15 P. M. The following are the readings taken:

Time	Volts	Amperes	K. V. A.	Remarks
2.15	135	300	40.5	Started to charge scrap, 50 lbs.
2.25	144	350	50.3	
2.30	140	360	50.4	
2.35	135	365	49.2	
2.40	133	370	49.2	Charging finished.
2.50	133	370	49.2	
3.00	130	376	49.5	Shut down to change connections.
3.06	120	350	42.0	Started.
3.15	120	350	42.0	
3.30	120	350	42.0	
3.45	120	350	42.0	
3.56	120	350	42.0	Teemed 43 lbs. and took sample No. 1.
4.00	125	300	37.5	Started.
4.12	146	350	51.1	Started charging 50 lbs. electrolytic nickel.
4.15	137	388	50.4	
4.18	124	375	46.5	Charging finished.
4.22	123	370	45.5	Complete melt.
4.24	106	325	34.5	
4.30	115	350	40.2	
4.35	115	350	40.2	Teemed 50 lbs. Sample No. 2.
4.37	128	330	42.2	
4.41	128	330	42.2	Started charging 50 lbs. electrolytic nickel.
4.45	132	337	44.4	
4.48	129	340	43.8	
4.51	130	350	45.5	
4.54	126	357	45.0	
4.57	125	360	45.0	
5.00	124	361	44.8	
5.03	122	362	44.2	
5.05	121	366	44.3	Charging finished.
5.06	122	368	44.8	Complete melt.
5.10	120	368	44.1	
5.20	94	342	30.2	

The metal was kept in a molten state, and the following morning at 11 o'clock sample No. 3 was taken. Nothing further was done until two mornings afterwards, the metal meanwhile being maintained in a molten condition. This delay was caused by the absence of a New York gentleman who desired to witness the work, who was unavoidably detained, and the metal was kept melted awaiting his arrival. On the morning of the fourth day work was resumed, the following readings being taken:

Time	Volts	Amperes	K.V.A.	Remarks
7.00 A.M.	106	235	24.9	
7.30	112	250	28.0	
8.00	112	250	28.0	
8.20	112	250	28.0	
9.30	125	265	33.6	
10.05	127	265	33.6	
1.00 P.M.	126	255	32.1	
1.20	130	262	34.1	
1.30	150	300	45.0	
1.45	150	300	45.0	Sample No. 4.
1.47	150	300	45.0	Started charging 34 lbs. electrolytic nickel.
1.50	148	307		
2.00	126	324		
2.10	126	300	37.8	
2.35	126	300	37.8	
2.40	148	350	61.8	
2.55	146	348		Charged 3 lbs. manganese.
3.00	146	348		Teemed. Sample No. 5.

The samples taken showed:

	1st Sample	2d Sample	3d Sample	4th Sample	5th Sample
Metallic iron	6.56%	1.45%	0.35%	0.39%	0.53%
Nickel oxide	nil.	nil.	1.25%	15.95%	11.40%

Sample No. 1 shows a great deal of iron, which possibly ocurred from iron scale falling from the baking-in ring. The iron decreased rapidly on charging further quantities of nickel, and from other causes.

It is not surprising that a great quantity of nickel oxidized, being kept molten for such a long period, and it is satisfactory to note the reduction of the amount of oxide on adding manganese.

Another point which would affect the nickel was that the men who had to watch the furnace over night were quite unfamiliar with the work, and maintained too high a temperature, as they were afraid of the bath freezing.

It will be seen that the melting was very rapid for the first charge, although the furnace was not very hot, and, including delays, took only 1½ hours, and in the second we commenced charging 50 pounds at 4.12, obtaining a complete melt at 4.22 and teemed at 4.35.

This work was experimental and consequently we were not working under the best conditions. The furnace was giving a power factor of about 90 per cent., therefore it will be seen that with an average kw. of 48.4, the power consumption for this

quantity was at the rate of 325 kw. hours per ton for melting only, which is very good for so small a furnace.

There are certain difficulties in melting the first charge, and, to overcome them, the first lot was melted in crucibles and poured into furnace. I will refer again to this difficulty in my next paragraph.

BRASS MELTING.

Very little work has been carried out in this country on brass and bronze, and, on that account, the information obtained is from England. The Grondal-Kjellin Company, Limited, 20 Abchurch Lane, London, E. C., worked on brass, and, when the ordinary furnace was used, were troubled with the "pinch effect," so well known to you all, through the constant reference to it by Mr. Carl Hering, who has made a study of the phenomenon. They overcame the difficulty by using a special crucible, together with specially constructed coil on the furnace, whereby the electrical conditions could be so changed that at any desired moment most of the current could be carried either by the metal in the bath or by the crucible itself. By this arrangement the crucible is first heated, and, when sufficiently hot, the brass scrap is charged. This soon melts, completing a circuit. The switch is then thrown over, and the metal itself carries most of the current; the crucible, when exposed, gradually becomes cooler, the cooling being visible.

After the first melt was obtained, 112 pounds of brass were charged and melted in about 30 minutes, with a power supply of about 30 kw., and twice the quantity only required 50 kw., melting in the same time. The first heating of the crucible required 42 kw. hours, and took 1½ hours.

The brass produced was remarkably sound, and, when tested against that produced in the ordinary way, showed excellent results.

In addition to this work, other experiments have been carried out on a 3-phase furnace, the lining being of firebrick. The result of these experiments shows a power consumption of 18 kw. hours per 100 kgs., or about 185 kw. hours per gross ton.

The "pinch" effect is far less intense in the use of 3-phase current as compared with single-phase.

As this work is still being carried out, it is not possible to give final results at the present moment.

There are now several small simple induction furnaces at work in this country, and abroad they are in regular commercial use.

There have been several very able papers which have been read on this subject, one of which was by Dr. Kjellin last year. These go well into costs and give so many details that these particulars have been purposely avoided, and, as previously stated, so much repetition is unnecessary, for all interested will, as a matter of course, look up previous papers.

THE COMBINATION INDUCTION FURNACE.

This is known as the Rochling & Rodenhauser furnace, and is used for melting and refining. The Rochling'sche Eisen & Stahlwerke, Volklingen, with their characteristic enterprise, were early in the field, and erected an 8-ton Kjellin furnace. They wished to obtain, for special purposes, a higher grade of steel than they were producing in the basic Bessemer converter, and attempted refining in the Kjellin furnace. Owing to the construction of this, they were unable to freely handle slags, and although able to refine, it was with great difficulty. The eventual result was that the furnace bearing their name was evolved from the Kjellin furnace, and the capacity has increased until now they are working a furnace which takes the full output of their generator.

It is interesting to note that it was their intention to refine ordinary steel to obtain steel of somewhat better quality, and they did not intend commencing the tool steel business, but now, as they have had so many requests and orders for large quantities of the high-grade quality, they have rapidly built up a large business, and are erecting a new plant at a great cost to take care of this.

It very soon became quite evident that the combination furnace had entered the field as a refiner, and is now in the first rank, accomplishing work which skeptics regarded as impossible.

You will find, on referring to pages 173-204 of Vol. XV, 1909 Transactions of this Society, a general description and costs of operation, etc., all of which can easily be followed by the help of the accompanying figures.

The refining is also well shown, and the writer cannot add much new matter to that paper.

However, a few particulars of observation personally made at the Volklingen Works may be of interest to you.

At the time of the writer's arrival, the 2-ton 3-phase furnace was in operation. Two casts of nickel-chrome steel were made. The following day the charges were for the production of high-grade silicon steel. These were produced from metal obtained from the basic Bessemer converter. Figures on these runs were not taken.

Wishing to get further particulars, samples of a heat were taken in order to follow up the refining, and at the same time electrical readings were also taken. These were as follows:

REFINING OF STEEL IN 2-TON 3-PHASE ROCHLING-RODENHAUSER FURNACE.

Time	Amperes			Volts		Kw.	Power Factor	Remarks
2.20								Charging molten metal.
2.30	128	128	130	310	320	45	0.70	
2.45	470	480	482	440	450	235	0.65	
3.00	490	495	505	485	495	275	0.65	
3.15	500	510	518	470	480	260	0.62	
3.30	495	510	510	460	465	250	0.61	
3.45	495	500	505	470	480	250	0.60	
4.00	485	495	506	470	480	272	0.67	
4.15	400	405	410	470	480	230	0.69	
4.30	373	377	390	490	500	205	0.63	
4.45	380	385	390	500	510	250	0.74	
5.00	505	508	518	475	485	263	0.63	
5.15	500	506	512	470	475	250	0.60	
5.18								Pouring out.

FURNACE OPERATIONS.

Weight of furnace and charge.....21,105 kilos.
Weight of furnace.....19,610 kilos.

Weight of molten steel..... 1,495 kilos.

2.25 Charging furnace.
2.27 Samples taken. Steel sample No. 1. Slag sample No. 1.
2.40 20 kilos lime and 6 kilos roll scale thrown on bath.
2.27 Sample taken. Steel sample No. 2.
3.00 4.5 kilos iron ore briquette added.
3.10 Bath stirred (to work in slag).
3.15 Samples taken. Steel No. 3. Slag No. 2.
3.17 30 kilos lime, 7 kilos roll scale, 4.5 kilos briquettes added.
3.20 Stirred.
3.22 7 kilos scale charged. Bath stirred.

Time.

3.30 55 kilos lime added.
3.35 Sample taken. Steel sample No. 4.
3.40 Rabbled well to work in very stiff slag.
3.55 Sample taken. Steel No. 5.
3.58 Removing slag (3 mins.). Slag sample No. 3 taken.
4.03 4 kilos slaked lime thrown in to gather up a small amount of remaining slag. Removed at 4.10.
4.13 Steel sample No. 6.
4.14 3 kilos Fe-Si added.
4.15 7 kilos retort carbon added.
4.16 Reduced current.
4.19 40 kilos desulphurizing slag mixture added.
4.23 5 kilos fluospar added to thin down the slag.
4.35 Rabbled. Slag fluid. Steel sample No. 7. Slag sample No. 4.
4.37 7 kilos slag mix, and 6 kilos Fe-Si added.
4.42 Rabbling. Weight of furnace and contents at this stage 21,050 kilos.
4.53 3 kilos Fe-Mn added. Steel sample No. 8. Slag sample No. 5 taken 5.57.
5.05 to 5.10 Temperature tests.
5.18 Pouring. 1.5 kilos Fe-Si added to ladle.
Steel sample No. 9 and slag sample No. 6 from ladle.
Weight of furnace, 19,645 kilos. Metal poured, 1,405 kilos.

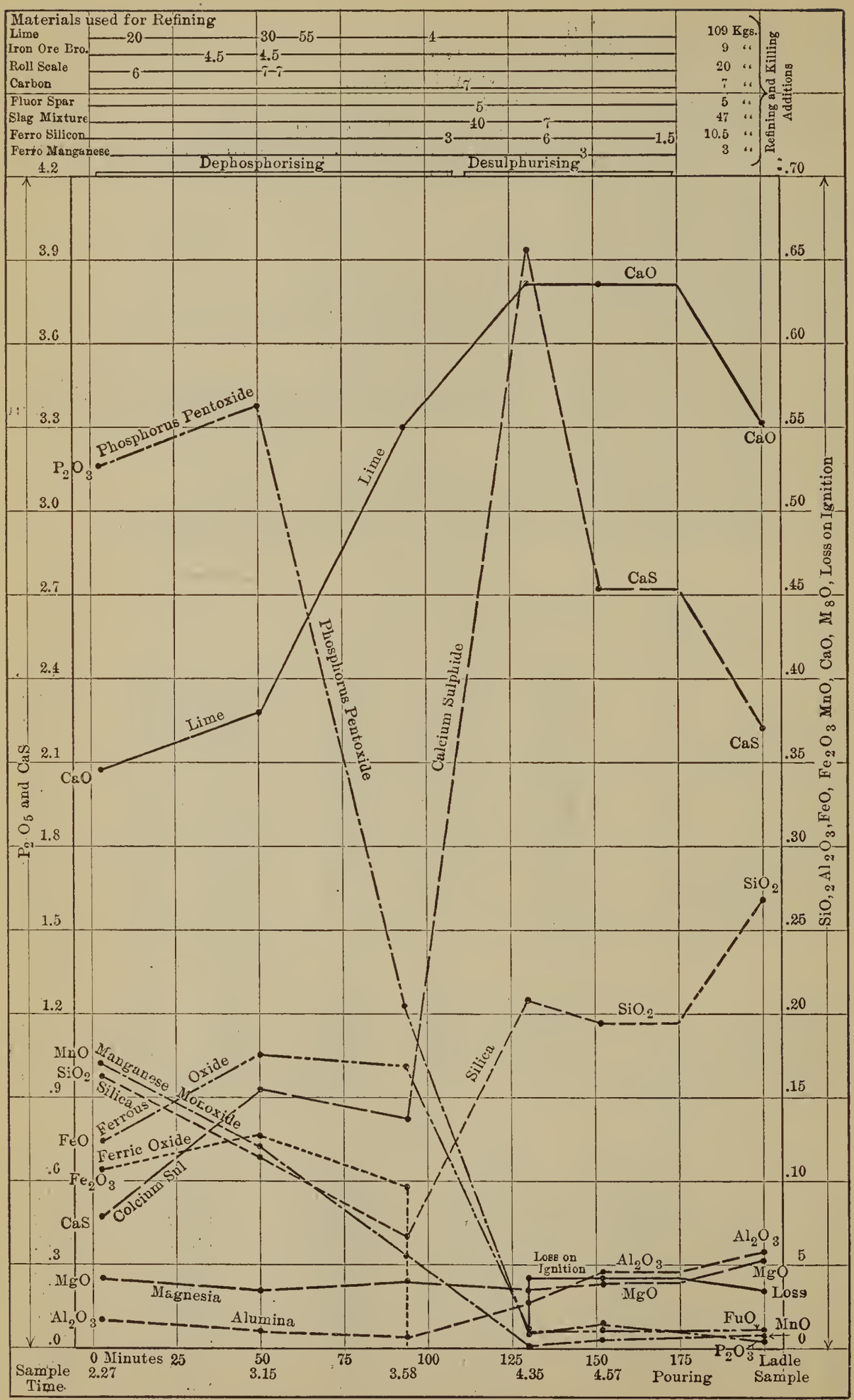
Analyses.

Slag Samples.

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Silica	16.11	11.28	6.51	20.72	19.40	26.72
Alumina	1.57	0.98	0.59	2.68	4.42	5.54
Ferrous oxide	12.43	17.51	16.78	1.05	1.12	0.93
Ferric oxide	10.73	12.59	9.71	....	....	....
Manganous oxide	16.89	11.90	5.52	0.18	0.50	0.74
Lime	34.57	37.93	55.01	63.60	63.53	55.40
Magnesia	4.13	3.44	3.84	3.47	3.88	5.21
Phos. pentoxide	3.16	3.39	1.24	0.055	0.078	0.023
Calcium sulphide	0.47	0.92	0.86	3.94	2.72	2.23
Loss on ignition	....	....	....	4.28	4.38	3.28
	100.06	99.94	100.06	99.97	100.02	100.07
Iron	17.33	22.43	19.84	0.82	0.87	0.72
Manganese	13.09	9.22	4.28	0.13	0.39	0.57
Phosphorus	1.38	1.48	0.55	0.024	0.034	0.010
Sulphur	0.21	0.41	0.38	1.73	1.21	0.99

Steel Samples.

	Carbon	Silicon	Sulphur	Phosphorus	Manganese
No. 1	0.08	0.005	0.069	0.070	0.41
No. 2	0.05	0.007	0.070	0.039	0.29
No. 3	0.04	0.011	0.075	0.014	0.19
No. 4	0.03	0.055	0.074	0.012	0.14
No. 5	0.03	0.002	0.060	0.007	0.10
No. 6	0.03	0.003	0.061	0.005	0.11
No. 7	0.56	0.013	0.033	0.012	0.16
No. 8	0.62	0.159	0.013	0.019	0.51
No. 9	0.60	0.165	0.011	0.021	0.51



Refining of Basic Bessemer Metal in a 2 Ton, 3 Phase R. & R. Furnace at Volklingen—Slag Samples.

The above particulars show that the refining took 2 hours and 58 minutes, and used up 653 kw. hours.

The amount of refining materials used was:

Lime	109	kgs.	at	$1.50	per	1,000 kgs.	0.16
Roll scale	29	"	"	4.00	"	" "	0.116
Carbon	7	"	"	5.00	"	" "	0.035
Fluorspar	·5	"	"	5.00	"	" "	0.025
Slag mixture	47	"	"	2.50	"	" "	0.117
Ferro silicon	10.5	"	"	62.00	per	ton,	0.651
Ferro manganese	3.0	"	"	45.00	"	"	0.135
							1.239 = 96c. per ton.

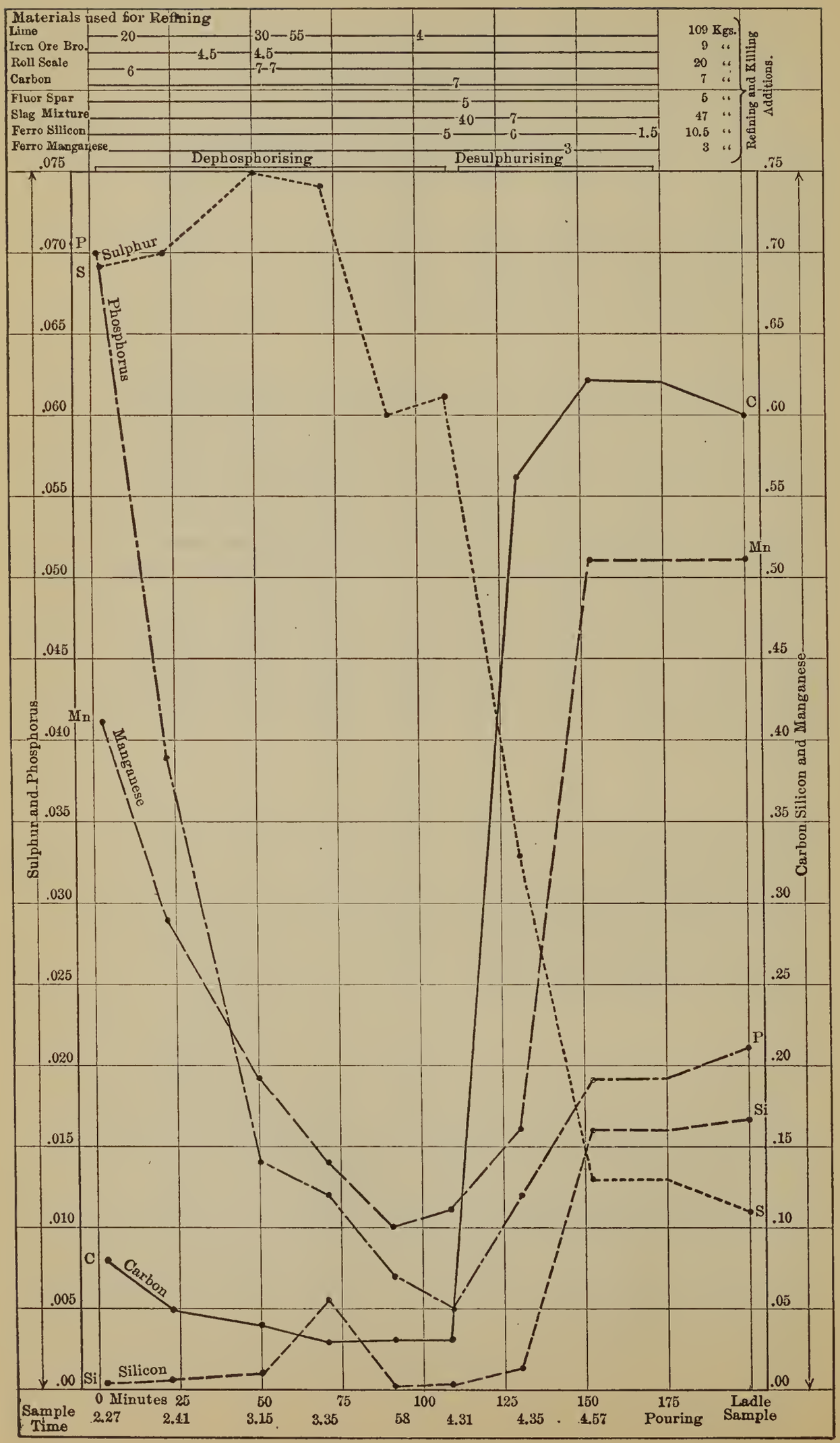
The total weight of steel tapped was about 1,500 kgs.

The above may seem costly, but at the Volkingen Works all the slag goes to the blast furnaces, so there is really very little loss, and consequently liberal use of these materials was made. Most of the lime was used to stiffen the slags in order to facilitate raking off. And, again, the steel was produced in a small furnace, which is always more extravagant than a large one. Had this furnace been working at its rated capacity, the refining material used would have been very slightly increased, when the cost of refining material would have been decreased to about 75 cents per ton.

Costs.

Power, 653 kw. hours per charge = 435 kw. hours per ton, at 0.5c. per kw. hour	$2.175
Refining materials, $1.44 per charge, per ton	.96
Labor, 3 men at say $3.00 per day, $9.00 production per ton, equals 4 charges at 1½ tons each = 6 tons	1.50
Lining costs, $52.00 for material and $20.00 for labor, $72.00; life, 12 days at 12 tons = 144 tons	.50
Repairs, say	.10
	$5.235

These costs look enormous, but, as before stated, the smallness of the furnace has to be taken into consideration, and here we have an estimate based on actual working for producing tool steel from molten basic Bessemer iron at a cost of only $5.25 per ton of ingots above the price of basic Bessemer ingots. This ought to appeal to tool steel manufacturers, especially as all grades of steel are produced, for the writer witnessed the production of all tempers of carbon steel, high speed, high silicon, nickel chrome,



Refining of Basic Bessemer Metal in a 2 Ton, 3 Phase R. & R. Furnace at Volklingen—Steel Samples.

tungsten and other steels in this furnace, which had just been erected and was new to the men, so that better results may be expected at a later date.

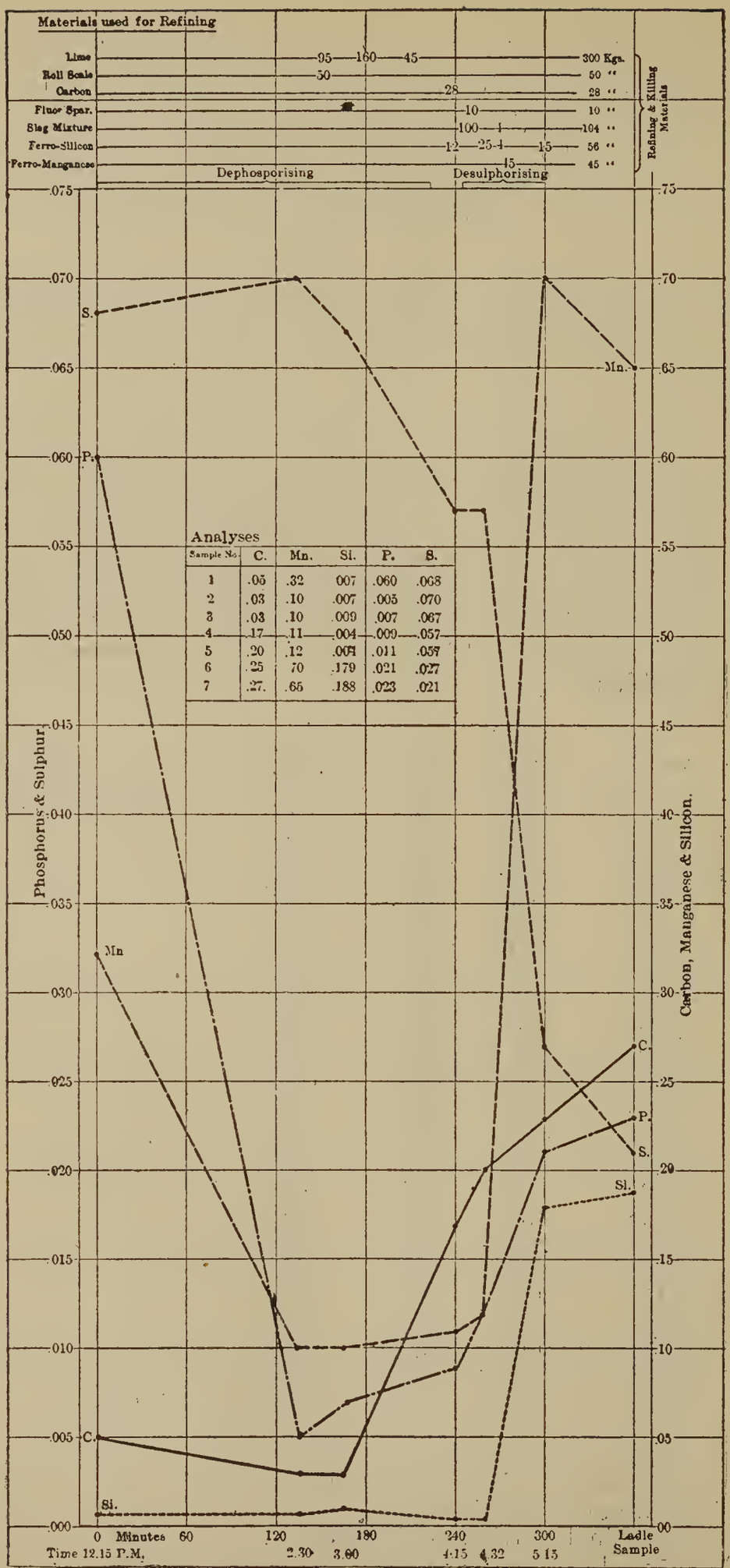
8-TON FURNACE.

This was witnessed in active operation. Here again all grades of steel were being produced, but, as the demand for alloy steels is not so great as that for carbon steels, the latter were predominant.

Again, molten metal was generally used for the charge, and, as the production of high-grade steel was taking place with monotonous regularity, there was really nothing to excite one's enthusiasm. Just as soon as they broke away from molten metal for the whole charge, and used part metal and part scrap, readings were taken and particulars followed up. These are given in the following tables:

Time	Volts	Amperes	K. W.	Power Factor	Remarks
12.15	4,000	138	440	0.79	Charged molten metal.
12.30	4,300	138	500	0.84	
12.45	4,300	138	500	0.84	
1.00	4,300	138	500	0.84	
1.15	4,200	140	500	0.85	
1.30	4,400	148	500	0.77	
1.45	4,620	156	600	0.85	
2.00	4,550	157	597	0.84	
2.15	4,500	160	595	0.83	
2.30	4,490	157	570	0.82	
2.45	4,500	160	580	0.81	
3.00	4,500	160	580	0.81	
3.15	4,500	160	580	0.81	
3.30	4,100	150	500	0.81	
3.45	3,900	141	455	0.83	
4.00	3,650	131	395	0.81	
4.15	3,570	123	355	0.81	
4.30	3,180	115	295	0.81	
4.45	3,180	115	295	0.81	
4.53	3,870	143	450	0.81	
5.00	3,870	143	450	0.81	
5.05	3,650	135	400	0.81	
5.15	3,650	135	400	0.81	Casting.

12.15 Charged molten Bessemer metal.....1st sample.
12.50 Charged portion cold scrap.
1.50 Charged final portion cold scrap.
2.30 All melted .....2d sample.
2.50 95 kilos lump lime and 50 kilos roll scale added.



Refining of Basic Bessemer Metal in an 8 Ton, Single Phase R. & R. Furnace at Volklingen.

Time.	
3.00	Slag fluid .....3d sample.
3.10	160 kilos lime added to stiffen slag.
3.30	Removing slag. 45 kilos lime added to stiffen remaining slag.
4.00	Removing slag.
4.10	Charged 28 kilos carbon and 12 kilos Fe-Si.
4.15	.....4th sample.
4.20	100 kilos desulphurizing slag mixture charged.
4.25	10 kilos fluorspar charged.
4.27	Stirred bath.
4.32	.....5th sample.
4.35	25 kilos Fe-Si thrown over slag.
4.38	Rabbled slag (brown color).
4.42	4 kilos Fe-Si and 4 kilos slag added.
4.45	Charged 45 kilos Fe-Mn.
4.50	Rabbled slag.
4.55	Rabbled slag.
5.00	.....6th sample.
5.15	Tapped.
	15 kilos Fe-Si added to ladle when casting.....7th sample.

APPROXIMATE AMOUNT OF STEEL, 6 TONS.

Fluxes, etc., Used	Kilos per Charge	Kilos per Ton				
Lime used (255 + 45)	300	50	at $1.00	per	ton	$0.05
Roll scale used	50	8⅓	" 2.50	"	"	0.021
Ferro-Silicon (12 + 25 + 4 + 15)	56	9⅓	" 66.00	"	"	0.616
Ferro-Manganese	45	7½	" 45.00	"	"	0.30
Desulphurizing slag mixture	104	17⅓	" 5.00	"	"	0.10
Fluorspar	10	1⅔	" 5.00	"	"	0.009
Carbon	28	4⅔	" 5.00	"	"	0.023
						$1.12

The steel was desired low in carbon, phosphorous and sulphur, and, on that account, extra refining materials were used.

Slag samples of this charge were not taken, as they are at best a matter of curiosity and cannot give any definite information, as most of the lime is used for mopping purposes only.

On referring to the time table and purification curve, it will be seen that the phosphorous was at its lowest just as soon as the cold metal was melted. The process of dephosphorizing was carried on for another 1½ hours, thereby consuming 800 kw. hours, together with a large quantity of lime and roll scale. The extra cost of these materials amounted to 6½ cents per ton, and the labor would be equivalent to about 20 cents per ton, and power 66½ cents per ton, the total amounting to about 93 cents per ton. The lining would also have produced extra tonnage.

This waste would not be allowed in this country, but, on considering that high-grade steel is produced, for which a very high price is obtained, the extra cost per pound amounts to 0.04 cent, which is very little.

This must not be regarded as the usual practice, but was due to a lack of care on the part of the workmen.

Not only did the extra oxidizing cost the 6½ cents for the lime and oxide, but, on calculating it out, it was found that the 28 pounds of ferro-silicon was required to take care of it, which is equivalent to 30 cents per ton, and the costs as previously given are really higher than they ought to be.

The total amount of power consumed was 2,400 kw. hours, equivalent to 400 kw. hours per ton, using part cold metal.

The costs, then, on this material are as follows:

Refining materials	$1.12
Power, 400 kw. hours, at 5c	2.00
Labor, 3 men $9.00, at 14⅖ tons per turn	.62
Lining	.30
	$4.04

But it has been shown that as much as $1.23 were wasted on power, labor, etc., to which must be added another 7 cents' waste on lining, making a total of $1.30 to be deducted; therefore the costs should be:

As observed	$4.04
Less waste	1.30
Cost should be	$2.74

In any case the figures given for a high-class steel are very good.

As has been pointed out very frequently, for the refining of molten basic Besseemr steel for electric steel rail quality the costs are very low, and attention is again directed to Dr. Kjellin's paper where, on pages 195 and 197, he goes into costs very thoroughly.

16-TON REFINING FURNACE.

The estimated costs of operation of a 16-ton furnace working on basic Bessemer steel, and refining to 0.03 to 0.035 per cent.

S. and P., and 0.50 to 0.80 per cent. C., are in accordance with the following:

SUMMARY.

	Per Ton
Materials charged	$15.10

POWER.

Heating, refining and cooling	0.535

WAGES.

On furnace	0.115
On lining	0.011
Lining materials	0.054
Repairs	0.190
	$16.005

License, tools, amortization and interest omitted.

MATERIALS USED.

2,240	lbs.	basic Bessemer metal	$14.00
42	"	burnt lime, $1.50	0.028
14	"	ferro-silicon, at $62.00 per ton	0.387
22	"	ferro-manganese, at $45.00 per ton	0.442
2	"	fluorspar, at $5.00 per ton	0.004
22	"	roll scale, at $4.00 per ton	0.004
11	"	crushed carbon, at $5.00 per ton	0.025
2,276	"	of metallic material	$14.890
68	"	loss 3 per cent.	
2,208	"	yield, costing	14.89
2,240	"	will therefore cost	15.10

POWER CONSUMPTION.

For Drying and Baking.

6,500 kw. hours, at 0.5c. per kw. hour., $32.50, say 2,400 tons per lining ..... $0.015 per ton.

For Refining.

100 kw. hours per ton, at 0.5c ..... 0.50 " "

For Cooling Fan.

40 kw. for driving fan at 0.5c. per unit ..... 0.02 " "

Total for power ..... 0.535 " "

WAGES PER 24 HOURS.

2 melters at $6.00 each	$12.00
10 laborers, cranemen, boys, etc., at $2.00	20.00
	$32.00

Daily production, say 280 tons.

Wages, per ton 0.115

Lining.

2 foremen, at $5.00	$10.00
8 laborers, at $2.00	16.00
Total per lining, 2,400 tons	$26.00
Therefore labor on lining per ton	0.011

Lining Materials.

Based on figures from Volklingen records, where dolomite mixture costs $7.00 per ton, as against $6.50 per ton here..... $0.054

These figures are based on continuous working and little or no loss of time between heats. One hour and twenty minutes is allowed from tap to tap.

There is no reason why this should not be done as a regular thing, for when working on rail steel in Volklingen on the 8-ton furnace this time was frequently reduced. What "held them up" chiefly was the fact that as they were dependent on the Bessemer plant, they could only obtain metal when it did not interfere with the operation of the mills, and on that account they were often waiting for metal.

The figures in table given are from a run of 42 consecutive heats on the 8-ton furnace:

Basic Steel		Electro Steel					Remarks
P.	S.	C.	Mn.	Si.	P.	S.	
0.049	0.061	1.01	0.33	0.15	0.020	0.022	For heating 4,994 kw. hrs.
0.059	0.065	1.04	0.33	0.18	0.012	0.024	
0.050	0.067	0.79	0.33	0.26	0.012	0.029	
0.060	0.069	0.16	0.33	0.015	Trc.	0.032	It was afterwards found
0.054	0.067	0.64	0.89	0.16	0.020	0.016	that the lime was run-
0.072	0.079	0.96	0.33	0.084	Trc.	0.014	ning high in sulphur,
0.067	0.067	0.51	0.83	0.15	0.026	0.018	which would account
0.048	0.059	1.20	0.33	0.12	0.015	0.020	for the erratic results.
0.055	0.087	0.92	1.06	1.12	0.018	0.020	
0.059	0.079	0.23	0.47	0.019	0.012	0.055	
0.053	0.071	0.57	0.87	0.24	0.018	0.029	
.052	.063	1.02	0.39	.18	.016	.018	
0.050	0.067	0.82	0.34	0.096	0.024	.016	

Basic Steel P.	Basic Steel S.	Electro Steel C.	Electro Steel Mn.	Electro Steel Si.	Electro Steel P.	Electro Steel S.	Remarks
.058	.061	0.80	0.37	.054	.021	.020	Most of the high sulphur
.059	.065	0.93	0.40	0.16	.020	.018	steels are low in carbon.
.043	.089	0.92	0.34	.070	.013	.024	
.070	.075	0.18	0.40	.024	Trc.	.038	
.072	.069	0.86	0.40	0.10	.023	.019	
.058	.081	0.62	0.96	0.16	.024	.020	
.060	.067	0.07	0.37	.028	Trc.	.059	
.056	.097	0.66	0.82	.066	.023	.032	
.089	.091	0.08	0.44	.024	.021	.030	
.076	.055	1.00	0.84	0.14	.010	.018	
.053	.123	0.10	0.40	.030	Trc.	.038	
.065	.079	0.93	0.87	0.11	.024	.020	
0.062	.071	1.01	0.84	0.19	.020	.024	
.078	.073	0.82	0.81	0.11	.025	.027	
.061	.067	0.88	0.31	0.25	.016	.032	
.051	.077	0.59	0.78	0.22	.019	.029	
.050	.059	1.06	0.75	0.20	.015	.024	
.035	.057	1.10	0.86	0.20	.013	.020	
.060	.063	1.10	0.34	.047	.015	.022	
.065	.079	0.98	0.34	0.23	.012	.014	
.071	.048	1.02	0.34	0.22	.013	.018	
.052	.077	0.83	0.87	0.20	.019	.020	
.064	.061	0.92	0.84	0.16	.020	.014	
.063	.063	0.83	0.79	0.13	.014	.012	
.060	.055	0.92	0.37	0.17	.010	.020	
.068	.075	1.00	0.23	0.16	Trc.	.024	
.072	.079	1.08	0.28	0.22	Trc.	.016	
.053	.065	0.88	0.76	0.13	.012	.020	
.075	.071	0.30	0.76	0.22	.014	.029	

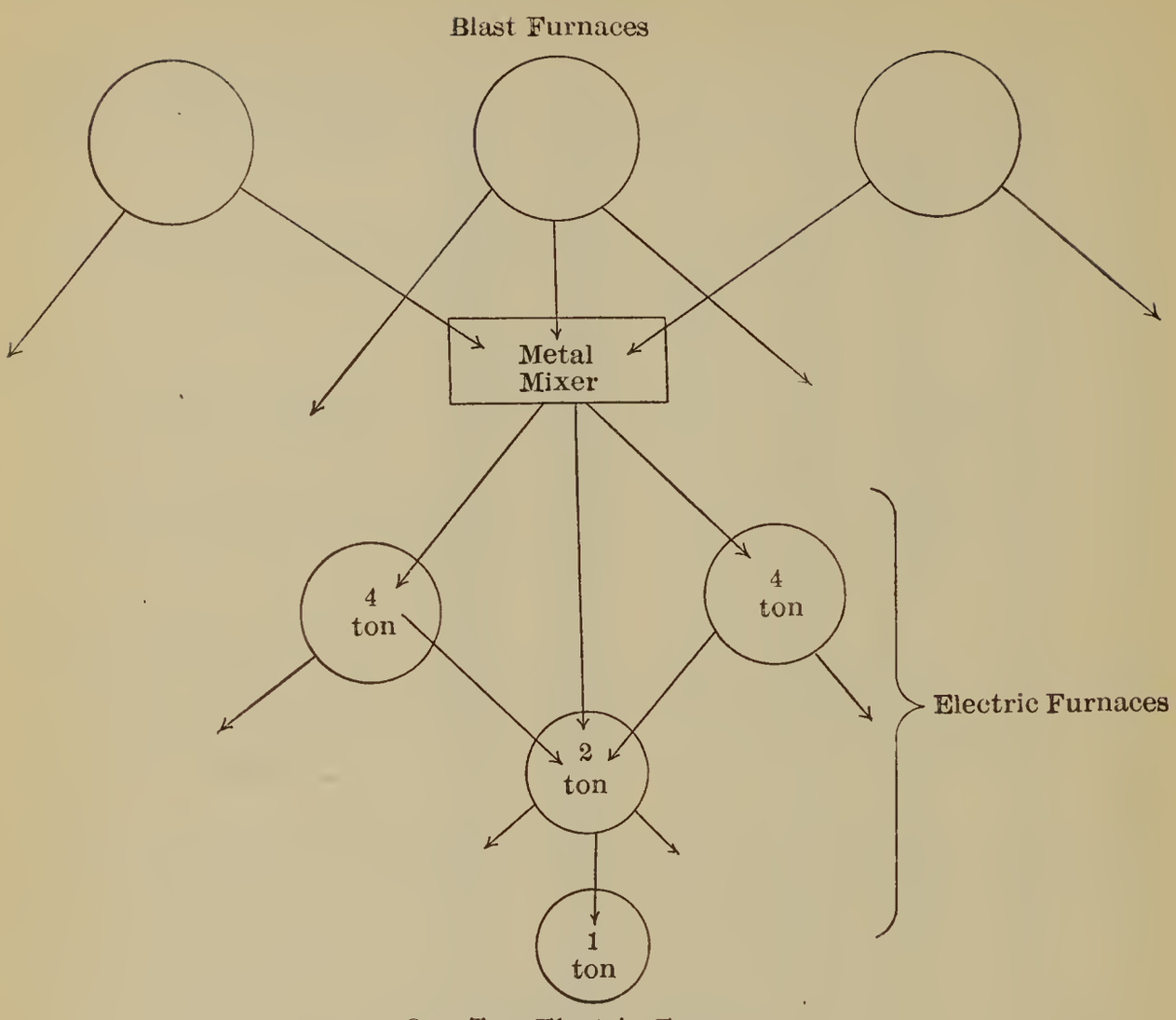
STEEL FROM PIG IRON.

So far the use of molten pig iron as the raw material from which to produce high-grade steel in the Rochling & Rodenhauser furnace has not been dealt with, but think it would be of interest to the Society if a few particulars were given of the work now being carried on by the Le Gallais Metz et Cie, Dommeldingen.

This firm commenced operations on a very small (1-ton) Rochling & Rodenhauser furnace. They were so satisfied with the results that they erected another of twice the capacity (2 tons). So encouraging were the results that they have recently erected two more furnaces of four tons each capacity, and have built quite a large electric steel casting plant.

The method they used was to take molten pig iron direct from the blast furnace, and, by numerous additions, eliminate the impurities until the desired composition was attained.

The new plant, which is just completed, is arranged as follows:



One Ton Electric Furnace

These furnaces are so arranged that they may be worked singly or in series.

The gas-fired mixer is of 25 tons' capacity, and was erected by Wellman, Seaver & Head, of London, England. In this mixer the Luxembourg pig iron is poured and treated by the addition of ores, lime and scrap, and is worked as an open-hearth furnace.

The pig charged is of the following analysis:

Carbon	4.0%
Manganese	1.3
Silicon	.7
Phosphorus	1.8
Sulphur	.15

and the finished mixer metal as charged into the electric furnaces in 3½ to 4-ton lots contains:

Carbon	.10 - .30%
Phosphorus	.05 - .07
Sulphur	.05 - .07

After treatment in the electric furnace, the steel, which is used exclusively for castings, runs:

Carbon	.07 - .10%
Manganese	.20 - .35
Silicon	.15 - .15
Phosphorus	.008 - .01
Sulphur	.008 - .01

The actual composition varies with requirements.

This refining is accomplished with two slags only.

As will be seen, the method is really a development of the electric furnace with which the casting business was commenced, and this firm have made provision for further development by allowing room for additional furnaces as the demand increases.

MELTING OF FERRO MANGANESE AND MANGANESE STEEL SCRAP.

Experiments were carried out at Niagara Falls to demonstrate the suitability of the induction furnace principle for melting this class of material. As these tests were of a private nature, the information obtained cannot well be made public. On this work the furnace proved an unqualified success, melting the materials with great rapidity, very slight loss of manganese content, and low power consumption.

A furnace has been erected in Germany to melt ferro manganese for a basic Bessemer plant.

The writer can only trust that this paper will be of some slight interest, for it only skims the surface, and it has not been intended to carry out any argumentative assertions, controversial points having been carefully avoided, but, before closing, the attention of all is directed to the very steady load which is so desirable in all electric furnaces and compensates for the apparent low power factor.

List of Induction Furnaces in Operation or in the Course of Construction.

Kjellin Type

Company	Capacity in Kilograms			Current	Kilowatts	Method of Charging	Application of product
	Working	Not Working	Building				
1. Fried. Krupp, A.G., Essen a.d. Ruhr, Ger. . .	8,500	. . .	. . .	Single Phase A. C.	750	Cold chg.	High qual. steel
2. Oberschlesische Eisenindustrie, A. G , Gleiwitz, Germany. . .	1,500	. . .	. . .	"	180	"	"
3. Poldihütte, Kladno, Aust.	4,000	. . .	. . .	"	400	Molten O.H. metal	"
4. L. Braun's Sohne, Vöcklabruck, Austria.	400	. . .	. . .	"	65	Cold chg.	"
5. Vickers, Sons & Maxim, Sheffield, England.	. . .	1,500	. . .	"	230	"	"
6. "	. . .	. . .	180	"	100	"	"
7. Wm. Jessop & Sons, Sheffield, England. . .	. . .	. . .	1,800	"	250	"	"
8. Alti Forni Gregorini, Lovere, Italy.	. . .	. . .	1,500	"	330	Molten O.H. metal and cold charge	Tool steels
9. Vidua de Urigoitia e Hija, Araya, Spain.	1,500	. . .	. . .	"	215	Cold chg.	High qual. steel
10. Eisenwerk Dommarfvet Gysinge, Swdn.	1,500	. . .	. . .	"	175	"	"
11. Sybry Searls, Ltd. Trollhattan.	2,000	. . .	. . .	"	300	"	"
12. General Electric Co., Schnectady, N. Y. . .	60	. . .	. . .	"	50	. . . .	. . . . .
13. Sheffield University, Eng. .	100	. . .	. . .	"	60	Experimental furnace	Experimental furnace
14. Natural Physical Laboratory, Teddington, England. . . .	. . .	. . .	. . .	"	10	"	"

KJELLIN-COLBY TYPE

Company	Capacity in Kilograms: Working	Not Working	Building	Current	Kilowatts	Method of Charging	Application of product
15. Irvington Smelting and Refining Co., Irvington, N. J.	300	. . .	. . .	Single phase A. C.	60	. . . .	. . . . .
16. Electro Steel Co. of Canada, Ltd., Welland, Ont.	750	. . .	. . .	"	150	Cold chg.	Tool steel
17. Grenagle Electric Co., Baltimore, Md. . .	. . .	. . .	. . .	"	20	. . . .	. . . . .
18. McGill University, Montreal, Canada. . .	. . .	. . .	. . .	"	10	Experimental furnace	Experimental furnace
19. Massachusetts Institute of Technology Boston, Mass. .	. . .	. . .	. . .	"	10	"	"
20. Rensselaer Polytechnic Institute, Troy, N. Y.	. . .	. . .	. . .	"	10	"	"

ROCHLING-RODENHAUSER TYPE

21. Röchlingsche Eisen und Stahlwerke, Volklingen, Ger. . .	7,000	. . .	. . .	Single phase A. C.	750	Molten basic metal	High quality material, rails, etc.
22. "	2,000	. . .	. . .	"	275	"	"
23. "	. . .	.	2,000	"	275	"	"
24. "	. . .	. . .	2,000	"	275	"	"
25. Pilger & Neidhardt, Frankfort a. m. Ger.	. . .	. . .	2,000	Single phase A. C.	275	Cold chg.	Steel Castings
26. Bergische, Stahlindustrie, Remscheid, Ger.	5,000	. . .	. . .	"	500	Molten O.H. metal	High quality steel
27. LeGallais, Metz & Co., Dommeldingen, Luxemburg.	3,500	. . .	. . .	"	380	Molten pig iron from mixer	High quality steel. Steel castings

ROCHLING-RODENHAUSER TYPE (Continued)

Company	Capacity in Kilograms: Working	Capacity in Kilograms: Not Working	Capacity in Kilograms: Building	Current	Kilowatts	Method of Charging	Application of product
28. LeGallais, Metz & Co., Dommeldingen, Luxemburg. .	3,500	. . .	. . .	Single phase A. C.	380	Molten pig iron from mixer	High quality steel. Steel castings
29. "	700	. . .	. . .	"	100	"	"
30. "	. . .	. . .	1,500	D. C.	275	"	"
31. "	. . .	. . .	3,500	Single phase A. C.	380	"	"
32. Acieries de la Marine et d'Homecourt St. Chamond, France. . . .	. . .	. . .	3,000	Direct current	350	Molten or cold chg.	High quality steel
33. Acieries Liegeoises, Bressoux-les-liege, Belgium. . . .	. . .	1,000	. . .	"	200	Cold chg.	War material
34. Kropwerke Ziotooush, Russia.	. . .	. . .	1,000	"	175	"	. . . . .
35. Richard Honey, Mexico. . . .	. . .	. . .	2,500	"	300	Molten pig iron with ore additions	High quality steel
36. Berndorfer Metallwarenfabrik, A. Krupp, Berndorf. . .	. . .	. . .	. . .	. . .	. .	For the treatment of Nickel and Nickel Alloys	

A paper presented at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 7, 1910, President L. H. Baekeland in the Chair.

A NEW ELECTRIC STEEL FURNACE.

By A. L. Queneau.

In the operation of some types of electric furnaces, particularly those designed for the working and refining of iron and steel, serious difficulties have been noted, due to the so-called "pinch effect," these difficulties sometimes resulting in the complete interruption of the operation of the furnace. This "pinch phenomenon" has been heretofore regarded as disastrous, and a matter to be absolutely avoided. I turn this "pinch effect" to useful account in a new type of furnace, employing it as an auxiliary to the electric furnace operation and, particularly, making it available as a means for more thoroughly mixing and refining the charge.

It has been found that by providing the bath of metal to be treated with a connection consisting of molten metal subject to the hydrostatic pressure of the bath, and by appropriately proportioning the electric current passing through said connection to its cross-section and to the hydrostatic head, it is possible to produce in the metallic connection and in close proximity to the bath a series of impulses, or pulsations, within the molten metal, which are due to a series of disruptions of the molten metal in the connection and an alternate series of reëstablishments of the connection.

These disruptions are exhibitions of the action of the "pinch phenomenon"; the reëstablishment of the electrical connection in the molten electrode after each disruption is produced by the hydrostatic head of the superjacent metal in the hearth. The chemical conditions at the place where the "pinch effect" occurs being always reducing, there is no possibility of oxidation of the disrupted surfaces, and consequently no interruption of the furnace operation.

A small furnace, for demonstration purposes, of 500 pounds (225 kg.) capacity is under construction, and I hope to be able to present detailed results of furnace tests in a subsequent paper.

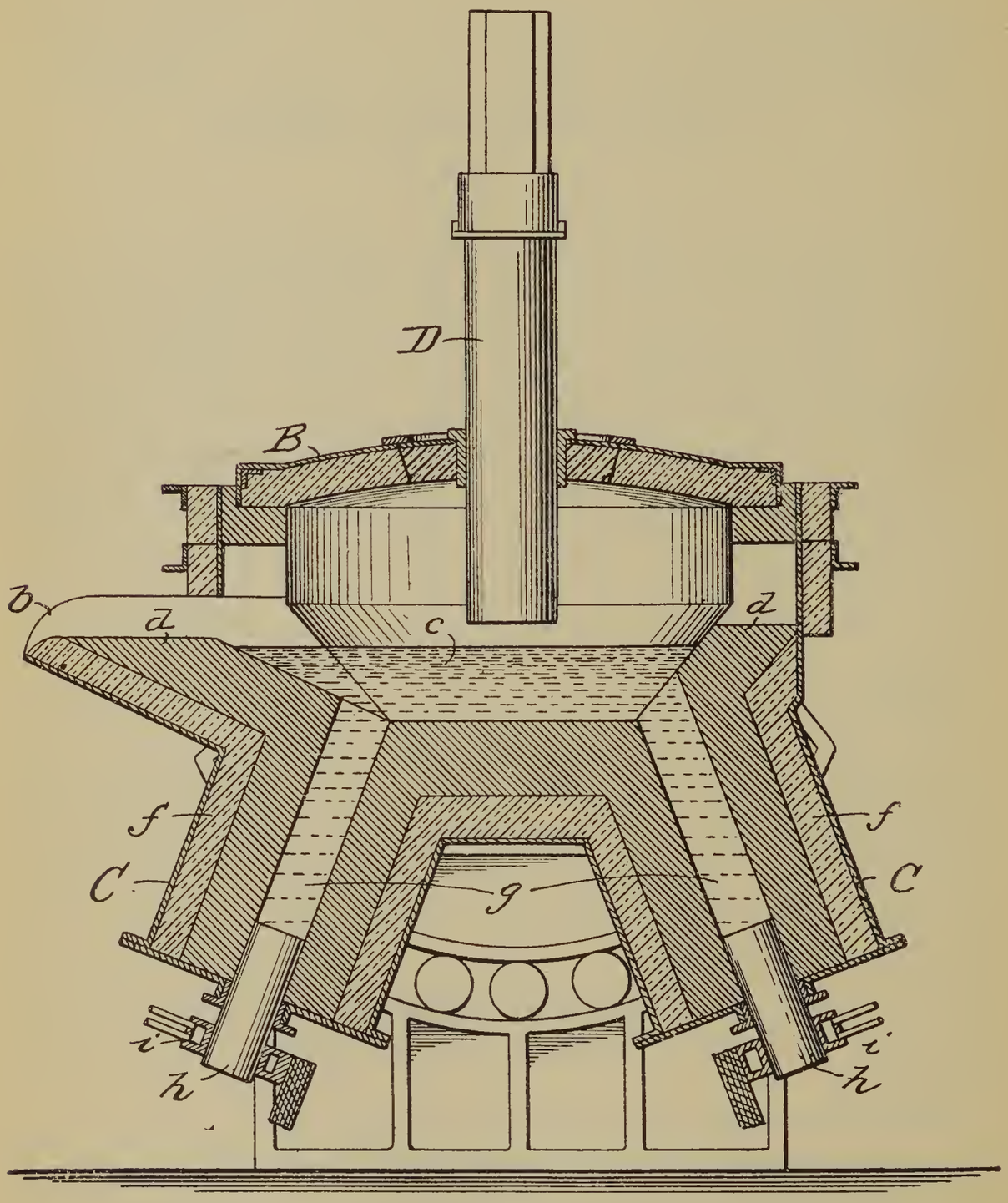


FIG. 1.

In the sketch is shown an adaptation of the principle to a tilting steel furnace. The current is used not only to produce the "pinch effect" in the molten metal connections from the bath, but also to develop the heating effect of an arc produced between an upper

electrode and the bath or the slag floating on the bath. This furnace may be used for either direct or alternating currents.

The branches, C, and the hearth of the furnace are lined with the usual fire-brick lining, "f," and an inner lining, "d," of burned magnesia, mixed with pitch, and rammed in place, the lining for the roof being of silica brick. The legs, C, are placed at a small angle from the vertical, thus converging upwardly toward a common central point, the central opening in the roof, through which passes the carbon electrode. This construction allows the repair of the rammed lining of the channels by inserting a steel former of suitable dimensions through the roof and into the channels, "g," whereupon the magnesia mixture may be rammed around the steel bar. These bars left in the channels are fused by the current and become part of the bath under treatment.

The metallurgical work is carried on in the usual manner.

In tapping the furnace care is taken to leave the channels filled with metal, to facilitate re-starting on a fresh charge.

DISCUSSION.

MR. C. A. HANSEN: May I ask what refractory he expects to use at the point where it is constricted?

MR. QUENEAU: The usual construction of an open-hearth furnace is a mixture of dolomite laid in tar.

MR. HANSEN: It has been my experience that dolomite and tar, or magnesite and tar become "cheesy" at steel bath temperatures, so that with a rabble it is easy to scrape off a portion of the hearth surface. It doesn't seem likely that such a material will stand up under strains that the "pinch phenomenon" would induce. I remember an instance when, in deliberately crowding energy into a one-ton induction furnace, charged with only 500 pounds of metal, until rupture took place, pinch effect made the vicinity of the furnace dangerous. Molten metal was thrown very violently out of the crucible. This must indicate a pretty tough strain on the lining materials.

MR QUENEAU: This is used practically every day in work throughout open-hearth furnaces.

MR. HANSEN: The lining of an open-hearth furnace is scarcely put to the same strain as the lining at the constriction of the proposed furnace would be.

MR. CARL HERING: Has anyone had any experience with alundum in connection with this subject?

MR. HANSEN: I have used it as a lining to steel furnaces, with disastrous results.

A paper presented at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 5, 1910, President L. H. Baekeland in the Chair.

THE PRESENCE AND INFLUENCES OF GASES IN STEEL.

By Dr. P. L. T. Héroult.

Blow holes in steel ingots invariably contain hydrogen and nitrogen, often with only traces of carbon monoxide. On the other hand, it is well known that when a thoroughly sound steel ingot is placed in a vacuum chamber, a certain amount of above named gases will be exhaled or thrown off.

The popular doctrine is that the percentage of the gases present is in proportion to the opportunities of absorbing same as a result of the process or methods employed in producing the steel.

But the quantities of gases so liberated in the course of thorough and repeated investigations have proven to be about the same, whether it be bessemer, basic or acid open-hearth, or crucible or electric steel.

In view of this, I have come to the conclusion long ago that these gases are absolutely innocent, and are not the cause of the production or presence of blow holes.

Blow holes are the result of disengagement of carbon monoxide, with the exception, of course, of accidental blow holes due to the poor condition of the molds.

This carbon monoxide does not pre-exist in the steel; it is only produced when the steel cools down and part of it has become solid. Steel that will produce blow holes contains in the molten state carbon, and, at the same time, iron protoxide. As long as the steel is molten and hot, those two bodies can keep apart, and for each temperature and each composition of steel, there is a state of equilibrium at which no chemical reaction takes place. The heat is then what the Germans call "Gar," that is to say, dead-melted. If the temperature is increased, the reducing action of carbon will be intensified and carbon monoxide will be evolved. If, on the contrary, the temperature is lowered, nothing happens till the steel gets partially solidified, with the

effect that carbon and iron protoxide are crowded in a small space, in what we might call the mother liquor, and monoxide of carbon is evolved. The blow holes produced are filled with carbon monoxide at a high temperature. As this gas cools down, however, it creates a vacuum, and we then repeat the conditions of the ingot in the vacuum chamber.

You can understand now why it is that blow holes are found containing hydrogen and nitrogen. Steel does not contain any gases to amount to anything, and whatever small quantities it does contain are not injurious or detrimental to its quality. As a matter of fact, bessemer steel, either acid or basic, which has every possible opportunity of absorbing gases, does not contain any more than any other steel.

DISCUSSION.

DR. R. AMBERG: The very interesting remarks of Dr. Hèroult deal with a question of highly actual importance, and I beg to permit me to ask your opinion about a certain point, as I have just done some preliminary experiments in a similar direction.

I need not call your attention to the well-known recent work of some French authors on gases in steel. It is stated that the amount of gaseous impurities ranges within the limits of usually low sulphur and phosphorus analysis. *Boudouard,* in Revue de Metallurgic, and *Belloc,* in Bull. Soc. d' Encour., both worked in a vacuum and found that the steel exhales gases only after a continued treatment, a certain time which in all cases was longer than industrial processes would allow to apply.

Corresponding about the matter with friends in Europe, I got just a few days ago copies of several patents of Girod. He claims to get a metal free from gases by cooling a superoxidized bath or a bath still containing a certain amount of combustible elements down to several low temperatures by means of cold scrap; to 700°-900° C. in one case, to 1100° in another, and says 400°-500° would be still better if attainable.

Now, I have tried to perform this alleged reaction both in superheated and in non-superheated steel in an electric furnace,

and could not observe any evolution of gases below, say, 1200°. In the first moment, of course, while throwing cold metal in a hot furnace of about 1800°, a development of gases takes place which is due to quite another cause.

You would oblige me, Dr. Hèroult, by giving your opinion about the possibility of applying propositions like this or similar ones to industrial practice.

Dr. Heroult: Well, if I understand, you speak of cooling steel down to 1200° C. Why, steel is solid there. It does not move there. Lower down, at 400° C., it does not move there. It is a solid substance there. No gas can evolve there unless you put it in a vacuum.

A paper presented at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 5, 1910, President L. H. Baekeland in the Chair.

A STUDY IN HEAVY ALTERNATING CURRENT CONDUCTORS FOR ELECTRIC FURNACES.

By K. C. Randall.

When heavy currents are to be carried, the first thought of an electrical engineer will likely be: What is the voltage of the service; what currents are involved? What are the conditions under which the currents must be transmitted and what is the length of transmission? What section must the conductor be in order to satisfactorily meet the requirements?

Before going into the design of the conductor, the nature of the service must be investigated. Is close inherent regulation required, *i. e.*, must the elements of the circuit which reduce the terminal voltage at full load below the voltage at no load be practically eliminated so as to obtain a steady secondary voltage independent of the load; or is inherent regulation of small importance, such as where hand or automatic control is employed for adjusting the voltage or current of the system? The heating of the conductors must also not be overlooked, and to this end sufficient section must be provided in order that cool operation, signifying freedom from excessive conductor loss, is obtained.

Alternating Current vs. Direct Current Conductors.

When currents of 10,000 and up to 40,000 or 50,000 amperes are contemplated, conductors very heavy in section are immediately suggested. Viewed from considerations of resistance alone, the problem is quite simple, but to alternating current, unlike direct current, the simple resistance of a conductor is not a measure of its suitability. Alternating current does not take full advantage of the conductivity of an ordinary conductor; it does not distribute itself uniformly throughout the section, but favors the area near the surface and shuns the central areas of the conductor section. A portion of the center of the section of a cylindrical conductor might be removed without appreciably impairing the effective conductivity for the alternating current.

"Skin Effect."

The surface distribution of the alternating current is termed "skin effect," and is more pronounced for higher than for the lower frequencies; that is, as the frequency more nearly approaches direct current conditions, namely, zero frequency, so does the importance of "skin effect" diminish. With small conductors of ½" or even 1" in diameter, the "skin effect" at 25 cycles is negligible, but with a 2" round conductor the "skin effect" has already reached such a value that the effective resistance has increased 25 percent compared with direct current conditions.

For 60 cycles, the ½" conductor begins to experience a trifling increase in the effective resistance; the 1" conductor experiences an 11 percent increase, and the 2" conductor more than 80 percent increase, that is, its effective resistance is nearly doubled. Furthermore, this is true independent of the current density which is employed. For example, a 2" copper rod (at 20° C.) 78 feet long will carry 5,000 amperes direct current with an ohmic drop of 1 volt and an energy loss of 5,000 watts. With 25 cycle alternating current and the same current, the ohmic drop would be 1.26 volts and energy loss 6,300 watts; with 60-cycle current, 1.82 volts and 9,100 watts loss.

Effect of Frequency.

These considerations would lead one to infer that for 60-cycle service it would be necessary to practically double the conductor section and for 25 cycles to increase the section about 25 percent in order to comply with direct current conditions. This conclusion, however, is misleading, for if a 2" conductor had been increased 82 percent in section, the effective resistance of the conductor to 60-cycle current would still be about 25 percent greater than the original 2" conductor, to the passage of direct current. Fortunately, the conductance of heavy conductors can be improved even for fairly high frequency alternating currents without the excessive increase in section, as outlined above.

Influence of Shape of Conductor Section.

In additional to the sectional area of the individual conductor, the shape must be considered when alternating current is to be transmitted. For a given conductor area, as far as effective con-

ductance is concerned, the best solid sectional form is round and the poorest a thin, flat sheet. If the sheet be rolled into a thin-walled tube, it represents less resistance than even the solid rod. Or the solid round conductor might be replaced by a laminated unit made up of a large number of separate small conductors, each of which has the same resistance and averages the same mechanical position throughout the length of the transmission. Each small unit would then be equally attractive to the alternating current, that is, each would carry a like current and the distribution throughout the combined conductor would be uniform and the "skin effect" would be eliminated. In practice, such an arrangement cannot be carried out conveniently, and approximations must suffice. It is reported that in some Swedish installations, concentric conductors have been used for carrying large currents. This plan has the advantage of practically eliminating self-induction and also has no external field which, in some instances, may influence measuring instruments.

Influence of Form of Circuit.

Besides the consideration of the individual conductor as to size and shape, it is necessary to go further and consider the form of the heavy current circuit, that is, the relative position of the coming and going conductors. Here the currents in the going and return conductors take the inner areas of closely adjacent conductors (as shown in end section by circles), thus not enjoying the full conductivity afforded by the conductor sections. The same remedy as for bad distribution applies, namely, laminating or breaking up into many individual conductors.

From the considerations so far, it is seen that in addition to considering the simple ohmic resistance which the direct current encounters in a circuit, it is necessary in alternating current work to contemplate the shape and size of the individual conductor and also the form and dimensions of the heavy current circuit. When these quantities are known, some means are available for lessening the burden of conductor losses which the alternating current experiences, so as to more clearly make direct current conditions apply.

This contemplates a single conductor in space. In practice a condition of an isolated conductor is rarely approached, nor will

a thin sheet be usually employed. This, therefore, is only of analytical interest.

In order to consider some of the limitations encountered in practice, an installation will be discussed.

In an assumed furnace installation operating at 100 volts, 25 cycles, the conductor arrangement and service are such that power factor of 90 percent is obtained at rated full load current.

Self-induction in Circuit.

By referring to the well-known right-angled triangle, in which 100 volts (the impressed voltage) is the hypothenuse and the base

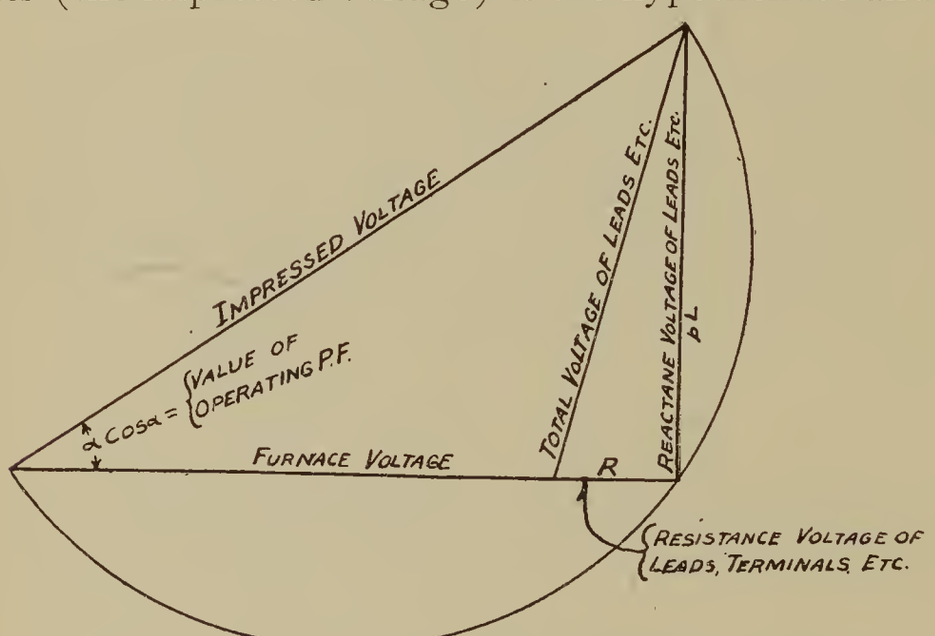

IMPRESSED VOLTAGE
α Cosα = {VALUE OF OPERATING P.F.
FURNACE VOLTAGE
TOTAL VOLTAGE OF LEADS ETC.
REACTANE VOLTAGE OF LEADS ETC. pL
R
{RESISTANCE VOLTAGE OF LEADS, TERMINALS, ETC.

FIG. 1. Condition for Maximum Energy in Furnace:

$$\text{Cos. } \alpha = 0.71 \sqrt{1 + \frac{R}{\sqrt{p^2L^2 + R^2}}}$$

(the useful or working voltage, in value according to the power factor) is 90 volts, we find the reactance volts (the value of the resulting altitude) to be 43. These 43 volts (the measure of self-induction in the circuit) cause little concern under the assumed conditions. But assume further that it becomes necessary to operate at 60 cycles. The reactance voltage is proportional to the frequency and current, so that on 60 cycles and the same current their value would become (60/25 x 43) 103 volts, or more than the total impressed voltage. This means that this furnace, even with the electrodes short circuited, would not quite take full current from a 60-cycle circuit, and similarly on the original 25-cycle circuit, something less than 2½ (100/43) times full load current would be delivered under short circuit conditions.

To increase the electrical input to a furnace necessitates an increase of current, since the voltage supply is fixed at 100 (the hypothenuse of the triangle). To increase the current, the impedance of the circuit must be reduced, and as the self-induction, determined by the design of the circuit, is fixed, it will be necessary to reduce the resistance, and this may be done through some adjustment of the electrodes. By referring to the figure, it will be seen that when the resistance is decreased, the line marked "furnace voltage" is shortened, and the side marked "reactance voltage of leads, etc.," has grown in such proportions that their resultant remains "impressed voltage." If the resistance were progressively reduced, the reactance would correspondingly increase until in the limit the line "furnace voltage" would disappear, and the lines "total voltage of leads, etc.," would coincide with "impressed voltage" under which conditions no energy would appear in the furnace. Similarly, if the "reactance voltage of leads, etc.," were reduced until it became zero, the "furnace voltage" line would coincide with the "impressed voltage" and a maximum input to the furnace would occur. For a given frequency and design of furnace the reactance voltage is fixed. Therefore, the only adjustment of the impedance must be by varying the resistance, and the condition for maximum energy is given in the expression under the figure, and in general will be approximately 70 percent.

For the assumed furnace, the maximum input (on 25 cycles) occurs when the base and altitude are each 71 volts, and is obtained when the current input has been increased to 165 percent. But the power factor has been reduced from 90 to 71 percent., so that the total power now is 165 percent current $\times$ 100 volts $\times$ 71 percent PF, or 118 percent, which is approximately 30 percent greater (not 65 percent), according to the increase of current, than obtained with normal current.

Capacity Limitation by Frequency.

For a 60-cycle circuit the normal full load current is much too large to give the maximum input. The base and altitude of the triangle become equal (each has a value of 71 volts) for this frequency when 69 percent current flows, corresponding to an input which is but 42 percent of the maximum 25-cycle input.

This ratio of 42 to 100 is the ratio of 25 cycles to 60 cycles, and in general *the maximum energy that can be fed into a circuit at different frequencies will be inversely proportional to the frequencies, and will exist at a power factor of 71 percent.* The assumed installation, though quite satisfactory for 25 cycles, would not be good for 60 cycles. A change in the arrangement of the conductor system so as to reduce the self-induction (reactance volts) would be necessary.

Capacity Limitation by Voltage.

If, instead of 100 volts, but 60 volts had been used, a maximum input of 36 percent would be obtained with 25-cycle current as compared with the maximum input for the 100-volt service. At 60 cycles the maximum input would be but 42 percent of 36 percent, or approximately 15 percent. Similarly an increase in the service voltage would increase the possible energy consumption. For example, 120-volts, 25-cycle supply would make the maximum input about 145 percent and correspondingly 60 percent for 60-cycle current. In general, energy *input to a circuit for a given frequency is proportional to the square of the impressed voltage.*

If there be an appreciable loss in the transmission circuit, the power factor of 71 percent for the whole system will not correspond to the maximum energy dissipation in the furnace, although it does give the condition for maximum energy in the whole circuit, including leads, terminals, electrodes, etc. The power factor corresponding to maximum energy in the furnace is dependent on the resistance (R) and the reactance (pL) of the feeding system, such as would be determined by measurements with short-circuited electrodes, and is the value of the expression:

$$0.71 \sqrt{1 + \frac{R}{\sqrt{p^2L^2 + R^2}}}$$

This expression has a value of 0.71 when R = zero (the condition assumed in the installation discussed), and the value unity when L = zero, a condition which can only be approached in ordinary practice.

As the function of an electric furnace is one of heating mate-

rials, and its capacity is in a measure determined by the amount of energy consumed in it, it may be said that the capacity of the furnace is determined by the maximum energy which can be dissipated within it, and this is determined by the operating power factor, as pointed out.

The influence of power factor on the capacity of the generating station is not discussed, but there is an evident relation of power factor to this part of a system.

The weight of conductors for very heavy currents is quite considerable, and good mechanical provisions must be made for their support. Besides having mechanical strength, the supports must be insulators, although the potentials involved will usually be only about 100 volts. The necessity for laminating and interlacing the conductors in heavy current work complicates the support problem. The contacts and connections between different parts of the circuit and the terminals of the apparatus, where the heavy current is to do its work, are also serious problems of this work.

A popular method of arranging conductors for moderate capacity installations employing 2,000 to 5,000 amperes is the use of a number of stranded cables disposed alternately of opposite signs (from opposite sides of the circuit), as in this way an effective interlacing is accomplished which terminates at the service point where the cables of like sign are joined to the proper terminals.

Besides the questions of self-induction and effective resistance as influenced by shape and size of conductor and form of circuit, there exists the additional question of the use of different materials, notably copper and aluminum for conductors. These materials offer different resistances to the passage of direct current, and their factors for "skin effect" are not the same. For the same section the factor is somewhat greater for copper, but practically the same for sections of equal resistance.

The efficiency of a heavy current conducting system is, in importance, on a par with the importance of the efficiency of the transformer and line from which the power will usually be obtained. Therefore, the question of loss in the heavy conductor system may be viewed in the same way as the loss in the other parts of the transmission and transformer system. And accord-

ing to the importance of these considerations will the warrant for expenditure to reduce losses be determined.

Low Power Factor Undesirable.

In the preceding it is pointed out that the conditions for maximum energy consumption in a circuit correspond to a power factor of approximately 70 percent, and although this is true, the conclusion should not be that a power factor of 70 percent is most desirable, because in general this is not the case; the higher the power factor the more satisfactory the operation. But it is interesting to note that where the furnace, or similar energy consuming device, must be forced to its maximum energy consumption from a constant energy circuit, this requirement does not permit operation with a high-power factor. The limitations under these special conditions are given in the following:

(1) The maximum power in a system containing reactance occurs when the total ohmic voltage (CR) equals 71 percent of the impressed voltage.

(2) The maximum power occurs in a furnace (resistance load) when the power factor of the system has a value given by

$$0.71\sqrt{1+\frac{R}{\sqrt{p^2L^2+R^2}}}$$

where R and L are respectively the resistance and self-induction in the feeding circuit.

(3) Input to a circuit for a given frequency is proportional to the square of the impressed voltage.

(4) The maximum energy that can be fed into a constant voltage circuit at different frequencies will be inversely proportional to the frequencies, and will exist at a power factor of 71 percent.

SUMMARY.

In general as a summary the following points may be noted:

The size and shape of conductors and operating frequency determine the magnitude of "skin effect."

The form and dimensions of the circuit and the frequency determine the self-induction.

"Skin effect" and self-induction are reduced by laminating

the individual conductors, by the selection of conductors of the proper size and shape, and by interlacing the conductors.

The reduction of the self-induction in the circuit is the most important and most difficult.

Pittsburgh, Pa.
April 18, 1910.

DISCUSSION.

MR. M. G. LLOYD: This subject of skin effect and inductance is a very important one, and there is one method of keeping both of them down which, I think, is not mentioned by Mr. Randall in his paper, and that is to use tubular conductors for both outgoing and returning leads, placing one inside of the other. The inner tube can be kept cool by flowing water, if necessary. This arrangement will keep both skin effect and inductance very low, and will be a much cheaper construction than stranding with transposition of conductors, and so I think should be taken into consideration by engineers. It has the additional advantage that there is absolutely no external magnetic field to interfere with measuring instruments, which can, therefore, be placed as close to the conductors as may be convenient.

MR. C. A. HANSEN: Mr. Randall has brought out a point which, though accessible in any electrical library, is very often overlooked by the very persons who should, from the nature of their work, pay most attention to it. Electrochemists more than any others are forced to deal with very heavy alternating currents, and the heaviest of these currents are used in resistance furnaces, where the designer is forced to use a return circuit widely separated from the furnace core which is to be heated. This circumstance materially limits the power factors obtainable at ordinary frequencies, even when reactance in the leads from transformer to furnace is negligible. One is prone to consider the permeability of air as unity and therefore negligible, and to merely avoid iron in the neighborhood of his conductors, sacrificing presumably slight efficiencies to be gained in power fac-

tor (by assembling all conductors closely) to simplicity of construction and insulation, which involve rather widely spaced conductors.

That this procedure can bring about deplorable operating conditions is shown by the following notes on an actual installation, in which furnace and transformer terminals are not separated by more than 20 feet.

Furnace—

Resistance.....0.00188 ohms
Reactance.....0.00107 "
Load ..... 610 kw. (18000 amps.)
Power factor..... 88.2 percent

Copper leads and transformer—

Resistance.....0.000141 ohms
Reactance.....0.00173 "
Load ..... 45.5 kw. (18000 amps.)
Power factor..... ± 1 percent

System—

Resistance.....0.002021 ohms
Reactance.....0.00280 "
Load ..... 655.5 kw. (18000 amps.)
K V A..... = 1075
Power factor..... 61.2 percent

Since this load is carried single phase on an otherwise balanced three-phase system, the power station is not in love with this furnace, and steps are being taken to re-assemble the copper.

The following table is characteristic of the furnace, which is such that the reactance is constant, while decreasing resistance causes the current to rise steadily on a constant potential of 64.5 volts:

Current Amperes	Resistance Voltage	Reactance Voltage	Total K. V. A.	Furnace Kw.	Total Kw.	Power Factor Percent
10,000	57.6	28.0	645	576	564	89.2
12,000	54.5	33.6	773	656	636	83.5
14,000	50.8	39.2	902	712	685	78.8
16,000	46.0	44.8	1,032	736	700	71.2
18,000	39.5	50.4	1,160	711	666	61.2
20,000	31.25	56.0	1,290	625	569	48.5
21,500	21.0	60.2	1,380	456	385	32.5
23,000	3.20	64.5	1,480	75	0	5.1

By reassembling the transformer-to-furnace-copper so as to eliminate the large loop enclosed by outgoing and return conductors, it is thought that the lead reactance can be decreased

from 0.00173 ohm to 0.00033 ohm, thereby cutting in two the reactance of the system without disturbing the furnace. In place of the above conditions as tabulated, there should result:

Current Amperes	Resistance Voltage	Reactance Voltage	Total K. V. A.	Furnace Kw.	Total Kw.	Power Factor Percent
10,000	62.5	14.0	645	611	625	97.0
12,000	61.8	16.8	773	723	741	95.6
14,000	61.0	19.6	902	826	853	94.5
16,000	60.2	22.4	1,032	926	962	93.2
18,000	59.0	25.2	1,160	1,017	1,062	91.6
20,000	57.6	28.0	1,290	1,096	1,152	89.4
23,000	55.6	32.2	1,480	1,205	1,280	86.7
25,000	53.8	35.0	1,615	1,257	1,345	83.3
46,000	6.10	64.5	2,970	0	276	9.3

With the same line current (all that really interests the power house in this case) the furnace will take 1096 kw., as compared with 666 kw. under the old conditions.

I have often heard it said that a furnace of this type wants its power in its own peculiar fashion, that it will keep on climbing rapidly on a constant potential supply until it reaches a certain current, and will remain constantly at that current for hours at a time. The explanation, of course, can be readily seen in the foregoing tables. The power drops off very rapidly after the furnace passes the 60 percent power factor value of current, and in all probability soon reaches a point at which no more energy is supplied than that which gets away at the terminals or into the furnace charge outside the core without necessarily reaching the walls. (The walls of this furnace are always cool at time of shutdown, but keep on getting hotter for the three days following shutdown.)

That the constant current finish of a furnace is due to lead reactance can readily be shown where a furnace is fed by cables lying looped on the floor. If the loop area is increased by kicking out the cables the current decreases, and *vice versa,* the current is increased when the cables are kicked together.

Since this meeting has been largely a "steel" meeting, it is also proper to call attention to the fact that some electric steel furnace men are using copper brought up along the back of the furnace to the electrode carriages in such a way that each conductor is practically surrounded by structural iron. This is the neatest and best way from the mechanical and furnace-man standpoint, but

it undoubtedly explains a great many low power-factor results. Ninety-seven percent power-factors are perfectly attainable in large capacity Hèroult furnaces by using overhead conductors, which are, however, unsightly and interfere with removal of roof and electrode by overhead cranes. Careful attention to design will surely bring about a compromise that will make it unnecessary for the power station to require the consumer to install a motor-generator set to supply his furnace, a condition some furnace men are facing at present.

In our own laboratory, where we are continually handling currents from 1,000 to 30,000 amperes at 40 cycles, we have not been seriously bothered with skin effect. We seldom allow more than 1,000 circular mills (0.5 sq. mm.) in copper per ampere when bare cables are used, and rather less in temporary bus-copper, yet the copper does not heat unreasonably. Inductance has, however, bothered us to such an extent in getting instruments to read properly that we have gone over, wherever possible, to bar copper—4 in. x ½ in. (10 x 1.25 cm.), 5 in. x ¼ in. (12.5 x 0.6 cm.), 10 in. x ¼ in. (25 x 0.6 cm.), and 6 in. x ½ in. (15 x 1.25 cm.) in section, and we invariably clamp outgoing and return bars together with the usual triangle clamps, using asbestos lumber the same thickness as the bar, as insulating separators. Where, as in our own case, the large number of heavy current experiments made necessitate frequent wiring and changes of wiring, the use of bar copper in place of cable has proved a saving in first cost of conductor, in better instrument agreements, in simplicity of wiring and inspection of same, and a very great saving in up-keep.

Mr. K. C. Randall *(Communicated)*: Mr. Hansen's contribution is very interesting and quite in line with what would be expected. He points out that the maximum input occurs at approximately 71 percent power-factor, also that constant potential furnaces have a fixed maximum input, which is determined principally by the distribution of the copper forming the supply circuit, and in this connection, Mr. Hansen also emphasizes, as in my paper, that the reduction of the self-induction is most important.

A paper presented at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 5, 1910, President L. H. Baekeland in the Chair.

DETERMINATIONS OF THE CONSTANTS OF MATERIALS FOR FURNACE ELECTRODES.

By Carl Hering.

Introductory. At the October meeting of this Society the writer read a paper on "A New Method of Measuring Mean Thermal and Electrical Conductivities of Furnace Electrodes,"[1] in which is described a proposed method devised by him for determining these important physical constants under electrode conditions. Since then he has carried out a series of these tests on four materials—carbon, graphite, iron and copper.

The purpose of the present paper is to describe the details of this test, to point out features which experience has taught, and to give the results. No attempt will be made here to compare or discuss the results or to draw conclusions from them, as this has been done in some of the writer's other papers.[2]

Briefly described, the method consists in imbedding a rod of the material to be tested in a heat-insulating material, allowing the two ends to project sufficiently for terminals. A steady current is then passed thru it which will heat it; it becomes hottest midway between the ends. The temperatures at the middle and at the ends, the voltage at the two ends, and the current, are then measured. From this data all the necessary physical constants are then calculated. The mean resistance is the quotient of the volts and the amperes; from this and the size of the rod, the mean resistivity is calculated. The product of the volts and amperes gives the heat flow in watts, which flows out at the two ends, and from this and the dimensions the heat conductivity

[1] These Transactions, 16, 317.

[2] The Proportioning of Electrodes for Furnaces. Proceedings A. I. E. E., March 1910.

Empirical Laws of Furnace Electrodes. Read at this meeting.

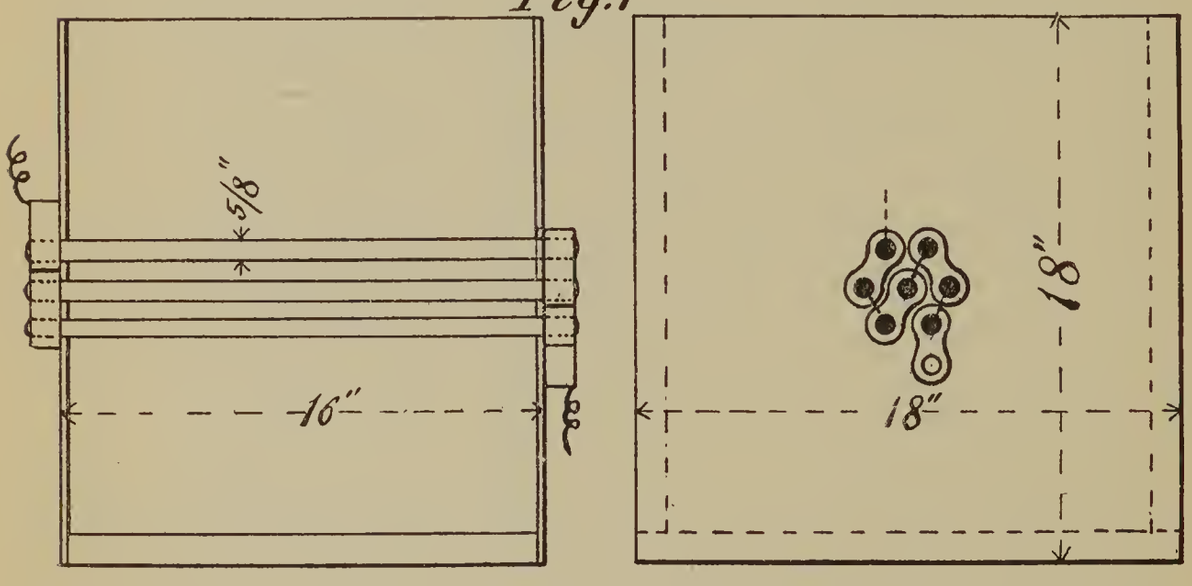
Properties and Behavior of Furnace Electrodes, Metallurg. and Chem. Engineering, March, 1910, p. 128.

Chilling or Heating Action of Furnace Electrodes vs. Least Electrode Loss. Ibid, April, 1910, p. 188.

Improving the Output and Efficiency of Existing Electric Furnaces. Ibid, May, 1910, p. 276.

is calculated. The rod is equivalent to two electrodes butting together at their hot ends, the interior of the furnace itself being omitted; hence the entire flow of heat is that due to the resistance of the electrodes, which is the condition under which a well-proportioned electrode should operate. The rod is assumed to be perfectly heat-insulated; this is nearly accomplished by surrounding it with a cage of similar rods thru each of which the same current passes. A stable state of temperature is of course essential, and the calculated constants are the correct mean values under electrode conditions; these mean values represent those

Fig. 1



which an equivalent electrode would have whose conductivities are the same from end to end.

General Description. The apparatus is outlined in Fig. 1. It consisted of a wooden box, about 16" cube, open at the top, and having two opposite sides made of thin asbestos board. A layer of fire-brick about 4" thick was placed on the bottom and two sides merely to fill up the space, so as to economize the finely-pulverized magnesite which was used to fill the inside of the box, and was packed tightly around the rods.

The electrodes were circular rods 18" long and about 5/8" in diameter. They were arranged as shown, the rod under test being in the center with six others like it arranged as a cage around it.

The couplings at the outside ends were water-cooled and were

soldered to the ends of the rods; this took up one inch at each end, leaving 16″ clear length of rods between terminals, thus forming two 8″ electrodes butting together at their hot ends. The couplings connected all the rods in series. The two for the two ends of the middle rod had slots cut into them, permitting a thermometer or thermo-couple and pointed wires for voltage measurements to be inserted to touch the electrode under test at the exact point of emergence from the furnace; hence the rod under test was exactly 16″ long, and the heat which might be generated in the contacts with the terminals was eliminated, as it should be.

A pyrometer was inserted with its end just over the middle point of the test electrode for measuring the high temperatures. The current was supplied by a motor-driven, separately-excited, direct-current dynamo of low voltage and high amperage. This was preferred to an alternating current because it was easier to measure such large currents and small voltages more accurately when they are direct.

A test consisted in passing a current thru the series of rods until the stable state of heat had been reached, as shown by the pyrometer. This temperature, those at the two ends, the drop of voltage between the two ends, and the current, were then measured. This was repeated for each of a number of different temperatures.

The tests were made at the well-equipped Electrical Testing Laboratories in New York City, and all but the special apparatus was supplied by it; much of the latter was constructed in its machine shop. The writer takes pleasure in expressing his appreciation of its excellent equipment and facilities. He was ably assisted by Mr. P. S. Snider, of that laboratory. A complete test took over three days for each material, including assembling and dismantling. This might be shortened somewhat if clamping couplings were used instead of those requiring to be soldered.

Detailed Description of Apparatus.

Materials. The tests were made with carbon, graphite, iron and copper. The carbon was obtained in the open market and was of the kind made for use as furnace electrodes. The graphite was obtained from the International Acheson Graphite Company.

The iron was purchased in the open market and was of the quality known as cold-rolled mild steel. The copper was the pure electrolytic metal of the best quality for electric purposes; the rods were obtained from the regular stock of a company making large electric apparatus.

The refractory material used for imbedding the rods was very finely pulverized magnesite, such as is used for furnaces. It is brown in color, quite heavy, and packs very tightly. It was packed dry, as it takes a very long time to dry it when it is used wet, and if dried too rapidly it cracks. At the higher temperatures, about 1200° to 1500° C., it turns white and the particles fuse together, there being apparently enough impurities in it to act as a binder. The fact that it turns white seems to indicate that the iron oxide is driven off.

An objection to it seems to be that it may not have been completely calcined, and that therefore some CO_2 is set free at the higher temperatures. This would probably combine with the carbon and graphite, and perhaps also with the carbon in the steel, forming CO. This may have been the cause of the deterioration which the carbon and graphite rods suffered at the higher temperatures and which limited the temperatures of these tests. The light, white magnesia was not used because it was thought that the very large amount of air which it encloses would oxidize the rods. No silicate of soda was used because it causes the material to be baked into a very hard rock around the electrodes, from which they cannot be removed for examination without injury.

Connections. The seven rods were connected in series with each other, as shown, by the couplings, so that the test rod was the middle one in the series, and the two at the ends of the series were located diametrically opposite to each other. This was done to minimize a leakage of current from one rod to the other thru the refractory material in case it should become conducting at the high temperatures. Except for very high temperatures, this precaution is probably entirely unnecessary, for even if there were some leakage it would probably be extremely small in proportion to the large current flowing thru the electrodes, which generally ranged from several hundred to several thousand amperes. The chief reason for so connecting them was

to meet any academic criticism on these grounds. It is, moreover, about as easy to connect them in this way as in any other.

Couplings. The coupling for connecting together the ends of the rods were made of brass, as shown in Fig. 2. The holes fitted the test rods loosely, so as to permit soldering the couplings on to the ends of the rods. They had a hollow chamber ½″ cube cast in them, into which passed two small tubes for the circulation of the cooling water.

To cast this chamber in the casting its core had to be supported by the two others for the round holes. This left an opening from the water chamber to each of the rods, and in soldering the couplings to the rods these were supposed to become closed. This was easily done with the iron and the copper rods, but with the

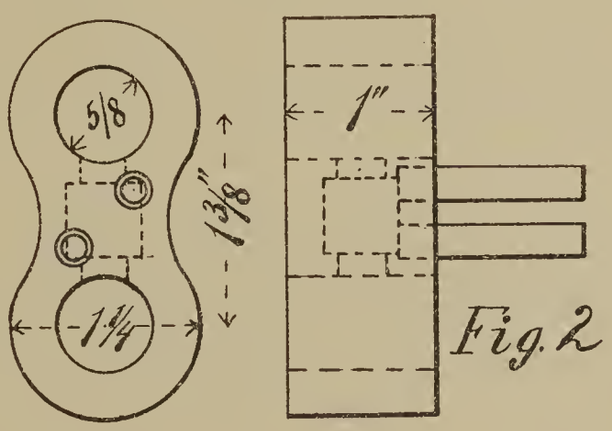


Fig. 2

carbon and graphite it was not entirely successful and gave rise to a slight leakage of water. The only objections were that it was sloppy and prevented using as great a water pressure as was desirable. It is mentioned here merely to show that this part might be improved should the test be repeated by others.

The advantage of having a single inflexible coupling for two ends is that only one cooling chamber is then required for two ends; this reduces the number of these chambers, with their equipment of rubber tubes, to only four at each end in place of seven. On the other hand, a rigid coupling may strain the test rods unless the holes and rods are quite accurately parallel. A flexible coupling would require a cooling chamber for each end of each rod, making 14 in all instead of 8.

The rods were all soldered into the couplings. They should be well tinned before assembling. The graphite and carbon must

therefore be first copper plated. This must be carefully done. If too thin, the tin will dissolve off the copper. If too thick, the expansion of the cylinder of copper during tinning by dipping will cause it to tear off. If the plating is stopped when the color is a light pink, and the tinning is done with an iron instead of dipping, good results will be obtained. High current densities and ordinary copper sulphate may be used if the rods are kept in constant motion in the bath. With about ½ ampere per square inch a very satisfactory coating was obtained in 10 to 15 minutes. When well tinned in this way the solder adheres so tightly that if pulled off it tears the outer layer of the carbon or graphite off with it.

Soldering the couplings on to the ends of the rod is tedious, but it probably forms an excellent heat conductor. With a clamped coupling it would probably be difficult, if at all possible, to keep the temperature of the cold ends down to 100° C. On the other hand, clamped coupling would save much time and trouble.

Each coupling was supplied with a separate stream of water less than an eighth of an inch in diameter and probably not more than a few inches of head; this flow at times carried off as much as one kilowatt; the water which entered very cold, came out scarcely warm to the touch. This shows the very large errors which one is liable to make by attempting to measure the outflow of heat by means of this cooling water. The fall of temperature between the assumed end of the electrode and the water was at times nearly 100° C., tho generally less.

It will be noticed from the drawings that the couplings were so disposed that an open space between two of them was left directly above the slot in the middle one so as to permit the voltmeter terminals and thermocouples or thermometers to be introduced vertically at one end and nearly so at the other.

Heat insulation. As the same current was passed thru all seven rods, they were all heated to approximately the same temperature, hence, after the refractory material around them had become heated as hot as it would get, there was no further heat flowing from the test rod into the surrounding material, hence it was heat insulated, all the heat in it being compelled to flow out thru the two ends.

This heat insulation was, of course, not perfect. The outer rods were necessarily at a slightly lower temperature than the middle one, but the difference could not have been great, as compared with the very great drop of temperature between the middle and the ends of the rods.

Electrodes are such very superior heat conductors as compared with the refractory materials, that any flow thru the latter would be only a very small percentage, and as the normal heat flow in an electrode is or should be about twice that which would flow by conduction alone, this already small fraction would again be halved. It seems therefore that the heat leakage may be neglected. There will of course be some heat flow parallel to the rods thru the material between them, and a part of this will be charged to the electrode. But in actual furnaces there will also generally be some leakage from the electrode to the walls, hence the error caused by this leakage, small as it may be relatively to the total, is generally in the same direction; it therefore seems to be even better in this test to have a slight leakage as it will then correspond better with actual cases.

Such a leakage must not however be confused with the heat required to raise the temperature of the refractory material, as that may be relatively very large. It is therefore a very important feature of this last test that sufficient time must be given to reach the stable state.

Temperature measurements. The high temperatures were measured with a platinum-platinumrhodium thermo-couple made especially for this test with long wires, the electromotive forces being measured with a potentiometer, thereby avoiding the error due to a current. The use of a potentiometer with this thermo-couple also enabled widely different temperatures and small changes in them to be measured with very great accuracy.

The great importance of this accuracy was not to measure the temperatures so closely, but to determine the stable state, that is, to determine accurately whether all the interior parts had reached their maximum temperature. This is important for the reason that the heat which is measured is that which enters electrically, and this is assumed to be the same in quantity as that which flows out thru the cold ends of the rods. If any of this heat is used

to heat up the materials it will cause an error in the results as that heat is charged to the flow thru the rods. It seems to take a very large amount of heat to raise the interior to the required normal temperature, and it would therefore create large errors to charge or credit any of this to the flow in the rods. When there are relatively few watts generated in the rod, as for instance with carbon, it takes a long while to reach this stable state, especially for low temperatures. This was not fully realized at the start and it is for this reason that the low temperature determinations for carbon are not as good as the others.

It is therefore of great importance in this test to be able to measure very small changes of temperatures, altho their absolute values in degrees need not be so accurately known.

If it is not possible to detect small changes of temperature, then to be sure that the steady state has been reached one should let the furnace run with a carefully adjusted constant current for a long while, several hours, before taking the readings.

The thermo-couple used in this test could be read to about 0.1° C., which corresponded to about one microvolt. It was carefully calibrated by comparison with another one which had been standardized by the Bureau of Standards. Its constant was about 100° C. per millivolt, and could be used between about 150 and 1,600 degrees. The hot end was protected by a quartz tube; the time lag of this tube was said to be only a minute or two which was quite negligible as compared with the hours which it took to heat the rest of the apparatus.

The cold end temperatures were kept approximately constant by regulating the streams of water. In the first tests they were estimated, but when it was found how accurately the constants of the materials could be determined by this method, these temperatures were later also measured with thermometers or a thermo-couple; this was done with the test of the copper and graphite rods, and it would have been better to have done it with the others also, especially for the lower temperature ranges in which this cold temperature becomes relatively more important.

The thermo-couple for the cold end was made of copper and constantan; its constant was about 20° C. per millivolt, hence much more sensitive than the other. It read to about 150° C. The junction was bare and was placed in direct contact with the

exact end of the electrode itself. It took less than a minute to acquire its steady state. There was no appreciable heat around the outside of the furnace, hence the cold junctions could be assumed to be at room temperatures.

Current measurements. The currents were measured by the drop of potential over an accurately standardized low resistance capable of carrying several thousand amperes. The drop was measured with a potentiometer. All the readings were roughly checked by means of a millivoltmeter.

Voltage measurements. The voltages were at first measured with a carefully calibrated voltmeter, but later with the potentiometer and were checked at times roughly with the voltmeter. The potentiometer was found to be preferable when accuracy is desired. It has the great advantage that it eliminates the resistances at the contact points.

The final standard of reference was a Weston standard cell. It was carefully tested before and after the test and was found not to have changed a tenth of a percent.

The pointed rods for making the contacts with the electrodes at the exact outer end, for the voltage measurements, were both of the same metal to avoid thermo e.m.f's, which might otherwise have been quite appreciable.

Potentiometer. The temperatures, currents and voltages were, as described, made with a well made and newly adjusted potentiometer which could be read to microvolts, as the divisions of about ¼ inch correspond to 10 microvolts. This bars out simultaneous readings, but these are not necessary as heat flows are very slow and give ample time for successive measurements. About three readings could thus be taken in two minutes, and as the stable state could be maintained for 15 to 30 minutes it generally gave ample time to get a good set of readings.

Test. The test consisted in passing a constant current thru the electrodes, and taking occasional readings of the pyrometer to see whether it had ceased rising. This may require several hours, depending upon the conditions. With carbon it takes longer on account of the small number of watts that can be generated. With copper it takes less time.

It seems inadvisable to try to hurry this by increasing the cur-

rent temporarily and then diminishing it to the normal. This seems to cause troublesome slow waves of heat which may make themselves evident later during the measured run; the lag or hysteresis effect of heat waves is very great. It was due to this that a number of runs had to be thrown out. It seems to produce false steady states. It may take half an hour or longer for such a heat wave to make itself felt. Moreover the relative distribution of heat along the rod seems to be different for different temperatures, hence incorrect results may be obtained by such a forced heating. The best results will be obtained by keeping the current constant. No measurements should be taken within a half or one hour after there has been any material alteration of the current.

When the steady state has been reached, several series of readings are taken of the temperatures, current and voltage, the number depending upon the constancy, and the degree of accuracy desired. It will be found that slight variations will make relatively greater differences in the value of the thermal conductivity calculated from them, as this is proportional to the ratio of two quantities (watts and temperatures) which increase at nearly the same rate. Hence when accuracy in this quantity is desired, the constancy of the readings should be quite great, especially of the temperature. If the latter goes up and down slightly it is safe to assume that the steady state has been reached. But if the change is in one direction only, the readings must be thrown out.

It has been shown in other papers by the writer that it is not necessary to know the thermal conductivity, as it is not by itself a measure of any good or bad property of electrode materials, nor is it by itself a factor for calculating electrodes; the same is true of the electrical resistivity. The true measures are the product and the quotient of these two conductivities, and these may be measured directly in this test. In that case such care to get consistent values of this troublesome thermal conductivity, need probably not be taken. The formulas for these will be given below.

After sufficient readings have been taken at one temperature the current is increased for another set and so on until the highest temperature has been reached. In the case of graphite and carbon this will show itself by a regular increase in resistance while the temperature is constant, showing deterioration of the rod.

TABLE I.

Detailed data of one run with Graphite.

Section 0.2918 sq. in. (1.883 sq. cm.) length 16 inches (40.64 cm.).

Time in Minutes	Amperes	Volts	Watts	Furnace Temp. C°	Drop in Temp. C°	Electrical Resistivity Ohm, cb. inch	Thermal Conductivity, Gr. Cal. per sec., cb. in.
0				356.7			
1	91.7	1.662	152.4		291.5	.0003305	.8561
2				355.4			
4	91.8	1.664	152.8		291.2	.0003305	.8589
5				356.0			
6	91.6	1.660	152.1		291.0	.0003305	.8557
9				355.1			
10	91.7	1.664	152.6		290.5	.0003309	.8601
11				354.8			
12	92.0	1.664	153.1		290.4	.0003298	.8632
13				354.9			
14	91.8	1.666	152.9		289.3	.0003309	.8656
16				354.6			
18	91.6	1.662	152.2		289.4	.0003309	.8614
19				355.1			
20	91.7	1.658	152.0		288.1	.0003297	.8642
21				355.2			
22	91.6	1.656	151.7		288.0	.0003297	.8625
23				354.8			
24	91.4	1.652	151.0		288.1	.0003296	.8582
25				355.5			
26	91.6	1.650	151.1		288.5	.0003285	.8578
Means	91.7	1.660	152.2	355.3	289.6	.0003302	.8605

Table I shows a sample set of readings at one temperature. It will be noticed that it was possible to keep the conditions very constant for quite long periods. The difficulty will be found to lie in getting constant values for the thermal conductivity. There is no difficulty in getting constant ones for the electrical resistivity.

Protection of the test rods. After the first test of the graphite rods, it was found by a cold resistance measurement, that the rod had been permanently injured by excessive heat; the whole test was therefore thrown out. Even the low temperature readings were of no use as the writer had not fully realized the great importance of waiting until the steady state had been reached. To charge the conductivity of the rod with heat that raises the temperature of the surrounding materials produces relatively

large errors in the calculation of the thermal conductivity; this heat involves specific heats as distinguished from steady flows of heat.

It was thought that this deterioration of the graphite was due either to the oxygen in the pores of the granular insulating materials, or else to the CO_2 gas which probably escaped from the insufficiently calcined magnesite. To protect the rods from either of these gases, they were in the subsequent tests covered closely with four layers of ordinary newspaper, then with three layers of thin asbestos cardboard alternating with two layers of newspaper. Either of these gases should therefore act on the carbon of the charred paper before reaching the rod and this should protect the latter.

While this seemed to do considerable good, and enabled somewhat higher temperatures to be reached, before deterioration started, it seems that these gases had not been the entire cause, hence the subsequent tests at the higher temperatures had to be thrown out also, as it was found that at constant temperatures the rod steadily increased in resistance, evidenced by the quotient of the voltage by the current; and after the test the graphite and carbon rods were found to have been changed from the middle points of their length for some distance toward each end.

Except for a short distance in the hottest zone for graphite, the charred paper was found to be still intact even to the extent that the printed letters on it were still distinctly legible, showing that no oxygen and presumably no CO_2 could have passed thru it to the rods. The entire cause of the deterioration had therefore not been found. This, and this only, limited the tests to the ranges given below.

The iron rods, which had been covered in the same way, showed that the asbestos had formed a compound with the iron in the hot zones. It would have been better not to have used it. The copper rods were wrapped in paper alone, and they came out quite clean, except at the hottest part, where some of the magnesite was rather firmly attached, the paper having been entirely consumed.

Current. It is important to know in advance approximately what current should be used to get any desired temperature,

because it takes an hour or two before the steady state for this temperature is reached, and if the current has been too great the test rods may be ruined. This current the writer endeavored to calculate prior to the test from such data as existed. It was soon found, however, that this data was not even approximately correct and therefore could not be relied upon at all; in fact, it even misled one, and was therefore worse than none at all, as it led to currents far in excess of the correct one, and this endangered the test rod. Now that this data exists, it would be very much easier to repeat the tests and to carry them out more accurately and more quickly without fear of exceeding the deterioration points.

With iron, for instance, the currents were so very nearly the same for widely different temperatures that only a small increase produced such a high temperature that it injured the rod slightly at the hot zones, probably melting and possibly even volatilizing some of the iron. This made the subsequent measurements less reliable. Had this very peculiar property of iron been known prior to the test, this excessive current could have been avoided.

When no such results as those determined by this investigation are at hand, a good rule to guide one in determining the proper current for producing a desired temperature is that for all materials the watts and the temperature drop increase very nearly, tho not quite, in the same proportion. Hence, by making a preliminary measurement of the volts and amperes it will enable one to calculate approximately what the temperature will be later on when the stable state has been reached with that current and voltage. This is of no use for the first point, but after the measurements for one point have been made, the ratio of the watts and temperature for this point can be used for the next one, and so on.

Water Cooling. The water-cooled couplings have been described above. Altho the water came out quite cool and even generally actually cold, it is advisable to connect the streams in parallel so as to be able to regulate the stream for any individual coupling which may be running hotter or colder than the others, as it is desirable to have them all approximately alike, particularly the two at the ends of the test rod. It is, of course, desirable to keep the cold end temperature the same for all the different

hot temperatures, and this can be done only by regulating the streams of cooling water. This is not essential, as the correction is easily made later by adding or subtracting the necessary amount to the high temperature to bring the lower one to, say, 100°.

There was no difficulty in taking care of even a kilowatt of heat flow by a stream of about 1/8" diameter and a few inches head. The greater difficulty lies in the apparently great thermal resistance between the water itself and the end of the electrode as it emerges from the furnace. This drop of temperature was sometimes nearly 100° C., tho generally less. There probably was too small a surface of contact between the water and the cooling chamber; this surface was about 1½ square inches, thru which at times as much as a kilowatt of heat flow had to pass to the water. A coupling with a spiral copper or iron tube cast into it would probably have been much better. If of iron, it should be tinned before the brass is cast around it, as the heat resistance of an unsoldered contact may become very high.

Calculated quantities. In the calculation of the derived quantities it must be remembered that there are two electrodes in series, and to avoid errors and confusion it is best to divide the voltage and the length by 2 at the start; all the calculations then refer to one electrode, and all the formulas in the writer's other papers then apply directly.

Care should also be taken not to confuse the furnace temperature with the drop in temperature. In all of the writer's formulas the temperature T represents the drop, and not that of the furnace. By adopting a uniform datum of 100° C. for the terminal temperature and reducing all observed data to this uniform one, this confusion is less likely to arise. This has been done in the other papers in which these data are compared.

Let E be half the voltage between the two outside terminals, L half the length in inches, I the current, T the temperature drop in centigrade degrees between the middle and the average of those at the two ends, S the cross-section in square inches, r the electrical resistivity, and k the thermal conductivity, both being the proper mean values under electrode conditions for each range of temperature.

Let the heat flow be expressed in electrical units, namely, watts,

instead of calories per second, as it simplifies the calculations and formulas and is quite correct, as watts and calories per second are exactly the same kind of a unit, namely a rate of propagation or flow of energy, that is, power. The conversion factors are : 1 gram calorie per second $\times$ 4.18617 = watts and watts $\times$ 0.238882 = gram calories per second. Since the writer called attention to this, others have endeavored to improve matters by giving this same unit the cumbersome name "watt-seconds per second." This is entirely unnecessary and complicates rather than simplifies.

The quantity E (half the voltage) can be obtained just as it is measured for each temperature drop without further deductions, as it gives directly the "watts per ampere," the use of which is described in the writer's other paper read at this meeting on "Empirical Laws of Furnace Electrodes."

The other important quantity described in that paper, namely S', the section per ampere per inch of length, is

$$S' = S/IL \qquad (1)$$

These are the only two quantities required for calculating electrodes, if the writer's method is used. But if in addition the quantities rk and r/k are wanted, the formulas are

$$rk = E^2/2T \qquad (2)$$

$$r/k = S'^2 \times 2T = 2S^2T/L^2I^2 \qquad (3)$$

If the electrical resistivity r and the thermal conductivity k are required, their mean values for each range under electrode conditions, that is, what the writer has termed the "electrode means," are

$$r = E \times S' \qquad (4)$$

$$k = E/2S'T \qquad (5)$$

The latter quantity k is not a very satisfactory one to calculate because it is proportional to the quotient of the watts divided by the temperature, two quantities which increase very nearly at the same rate.[3] Hence, unless the measurements are made very accurately, the values of k for the same conditions may not agree

[3] See paper on "Proportioning of Electrodes for Furnaces," proceedings of the Am. Inst. of Elec. Engr., March, 1910, fig. 6, p. 318. In this paper the results of these determinations are compared and discussed in detail.

closely, as small errors in the watts or the temperature drop in different directions will cause a larger error in k. This is one of the reasons why the writer recommended in his other paper read at this meeting, and in the other one just referred to, to abandon this quantity entirely in electrode calculations and use only E and S′, or the product and quotient, rk and r/k.

Table II.

Observed data.

The effective length of the rod (two electrodes) was for all the materials 16 inches (40.64 cm.). In the series marked with an asterisk (*) the rods had been slightly injured.

Reference Letter	Amperes	Volts	Furnace Temp. C°	Terminal Temp. C°	Drop in Temp. C°	Temp. variation in %	Duration in Minutes	Number of Sets of Readings
Carbon. Section 0.3147 sq, inch (2.030 sq. cm.).								
a	21.43	1.807	300.0	40.	260.0	. .	12	3
b	42.06	3.214	700.7	50.	650.7	1.0	30	12
c	49.19	3.709	902.0	60.	842.0	0.3	10	5
Graphite. Section 0.2918 sq. inch (1.883 sq. cm.).								
a	91.7	1.660	355.3	65.7	289.6	0.4	26	11
b	112.4	1.999	516.1	70.0	446.1	0.5	16	11
c	130.6	2.260	707.2	87.0	620.2	0.3	25	13
*d**	144.1	2.551	906.2	92.5	813.9	0.1	14	9
Iron. Section 0.30503 sq. inch (1.968 sq. cm.).								
a	370.3	.2869	347.8	50.	297.8	1.0	30	7
b	375.6	.5470	687.0	60.	627.0	0.2	23	6
c	377.9	.6412	876.8	65.	811.8	.1	18	6
*d**	412.1	.8636	1235.0	90.	1145.0	. .	. .	. .
Copper. Section 0.3088 sq. inch (1.992 sq. cm.).								
a	1797.	.0926	153.0	56.0	97.0	1.0	40	6
b	2101.	.1278	240.0	71.5	168.5	0.4	24	5
c	2366.	.1750	364.0	93.5	270.5	0.2	25	6
d	2613.	.2506	560.3	118.9	441.4	0.9	27	7
e	2748.	.3788	880.4	143.0	737.4	0.2	17	5

Results. The results of these series of tests are given in Table II. They are given here as they were measured, without any reductions to a uniform basis. The rods were not all exactly 5/8″ in diameter, and the cold end temperatures were not all the

same. For purposes of comparison it is desirable to have both these quantities uniform for the whole series. In the other papers in which these comparisons are discussed these slight reductions have been made, which explains the slight differences in some of the data. Attention may be called to the very steady state which had been reached in most of these runs and for a long enough time to get good sets of readings.

No attempt will be made here to discuss these data or to compare them as this has been done in the other papers already referred to.

Rods after the test. The appearance of the rods after the test showed some features of interest.

In general they all showed quite sharply-defined lines around the rods limiting the different zones in which various superficial changes had taken place. These lines were quite evenly distant from the middle point of highest temperature, thus showing close symmetry in the temperature distribution over the two halves. These were especially marked in the iron rod, a photograph of which is here reproduced in Fig. 3.

FIG. 3.

At the hottest part in the middle the iron had evidently been melted and the "pinch effect" had apparently acted to try to part it. In the next zones the asbestos and iron had combined into a very hard adhering scale for 1½" from the middle; this changed in color from brown to white at very sharply defined lines 3" from the middle. The white part was soft, and under the cooler parts of it, where the asbestos had not touched it, the iron had assumed a brilliant crystalline surface.

In the zones near the cold ends the iron looked exactly as it did at the start; it was not even colored, altho a current density of about 1600 amperes per square inch had been used. At the hottest part the surface of the iron under the glass looked like the lobes of a brain, scarcely visible to the naked eye.

The carbon and the graphite rods looked just as they did before the test, but upon examination of the surface in the hotter zones

it was found that a superficial deterioration had taken place, the surface having been changed in the carbon to a fine, soft, deep black powder, which could be easily scraped off with the finger nail. This was deepest in the middle, about 0.022″, growing less and less in depth for about 3″ to either side, where it ceased along a rather sharply defined line. The carbon underneath was softer than the original, showing that the deterioration had penetrated deeper.

With the graphite, this soft tho less powdery material had the same appearance and luster as the graphite itself, but could be scraped off with the finger nail. It extended to less sharply

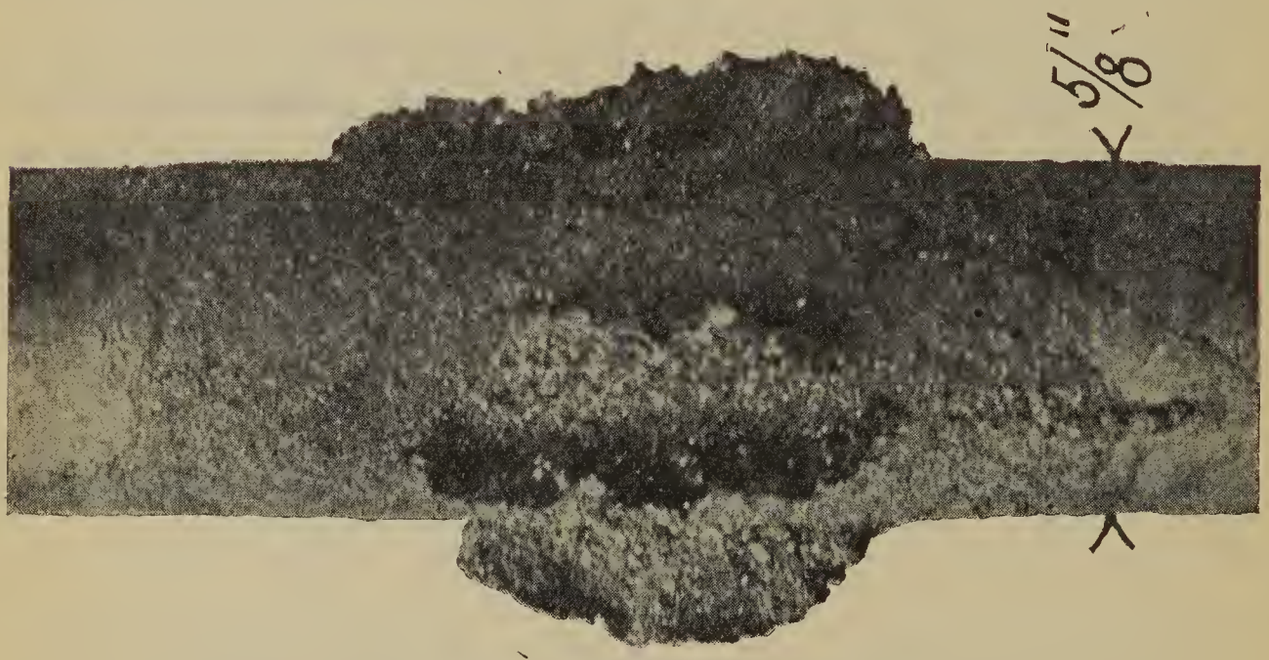


Fig. 4.

defined lines 1¼″ to either side of the middle; in the next zone, up to about 2″ from the middle, it was less soft. Its depth was not as clearly marked as it was with carbon. The graphite, even deeper down, cut more easily than the original. The paper around the hot zone had been completely consumed. An examination under the glass showed sharp, clean, deep little holes in the hot zone resembling those produced by a fine needle.

In connection with some of the deductions from these tests made in the writer's other papers, attention is here called to the fact that the deterioration of the carbon extended to more than twice the distance from the center than it did for graphite, altho the latter had been heated to a higher temperature. This indicates, tho it does not prove, the conclusion drawn from other

data, that in carbon electrodes the high temperatures extend much nearer to the cold end than in those of graphite, the latter behaving in this desirable feature more like the metals.

The copper rod showed a curious phenomenon. Apparently the maximum temperature had been just about that of its melting point and was a trifle higher in the core than on the surface, so that the metal had melted in the core for about an inch at the middle, while the outside was still solid. The result was that the outside shell had split, probably due to the expansion of the melted core, and the melted metal was forced out thru these thin, straight longitudinal cracks, forming thin webs, as shown in the enlarged photograph, Fig. 4.

An examination of the rest of the hot zone under the glass showed quite a number of small warts of copper, barely visible to the naked eye. They had evidently been melted in pockets in the interior and had been forced out thru pores.

The next zones of the surface of the copper had a white appearance like aluminum or silver; this layer was extremely hard and not extremely thin. It is not likely that it was an oxide, as the charred paper around them was still intact and the oxygen from the pores of the granular insulating material could not have reached the copper without having first passed thru these layers of carbon.

The zones near the cold end looked just as they did at the start and were not even colored, altho half a kilowatt of heat flow had passed thru the rod for a half hour or more, and less quantities for several hours, the current density having reached the very high figure of nearly 9,000 amperes per square inch.

No difficulties whatsoever were caused by the exceedingly high current densities used in some of these runs.

All the rods had been raised to higher temperatures than those recorded, as with all the materials the temperatures were raised until it was found by progressive changes of resistance (quotients of the volts by the amperes) under constant temperature conditions that deterioration was taking place. The last run was then discarded.

The reason why the writer's determinations were not carried to higher temperatures for carbon and graphite was that it was found impossible to prevent injurious deterioration due pre-

sumably to the gases in the granular refractory material used. If this is the cause of the deterioration, and if it cannot be prevented, one of the two following methods might perhaps be used for higher temperatures.

One of these, and no doubt the best, would be to carry out the writer's method in a vacuum furnace. The other would be to determine mathematically, if possible, how to calculate accurately the proper mean value from the two extremes; then to measure r and k at the high temperatures, say, in a vacuum furnace, and at the low one, and calculate the mean from them.

Philadelphia, March 7, 1910.

A paper presented at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 5, 1910, President L. H. Baekeland in the Chair.

EMPIRICAL LAWS OF FURNACE ELECTRODES.

By Carl Hering.

At the previous meeting of this Society the writer read a paper on the "Laws of Electrode Losses in Electric Furnaces,"[1] in which the laws governing the proportions of electrodes and the losses in them were deduced. The application of these to determine the proper proportions of electrodes requires a knowledge of the necessary physical constants, just as in most other formulas which the engineer uses in his work. These physical constants were in part either not known at all or only vaguely; the writer therefore determined those required for his formulas. These are given in detail, discussed, compared and prepared for use in practice in a paper on "The Proportioning of Electrodes for Furnaces," published in the Proceedings of the American Institute of Electrical Engineers for March, 1910, p. 285.

The purpose of the present paper is to analyze these experimental results with a view of finding, if possible, whether any of the physical properties involved follow some approximate general laws; and, if so, what these laws are and what use may be made of them in practical work.

The writer desires to emphasize at the outset that any such empirical laws are, of course, at best only probable laws, and not absolute. The degree of probability becomes greater the closer they agree with the actual measured results. If, moreover, the same general law is found to apply to different materials, the only change being in the numerical coefficients, the probability of its correctness is very greatly increased. If, furthermore, the law can stand the severe test of being extended beyond the ranges of the actually determined part without giving values which are known to be absurd or impossible, the probable correctness of such a law is still further increased, especially if these exterpolated values are such as are to be reasonably expected.

[1] Transactions, **16**, 265.

Take, for instance, the very common empirical law that the resistance of a pure metal increases with the temperature in a straight line proportion. If the extension of this line downward cuts the zero resistance line above the absolute zero, it is evident that it is not the correct law and should be extended only with caution; such a zero resistance is known to be impossible, because a still further extension would give a negative resistance, which means a generation of current. If the line tends to the absolute zero the probability of its correctness becomes greater. Such a law for carbon is known to be incorrect, because the resistance of this material is known to fall with a rise of temperature, hence the extension of the line would cut the axis at some higher temperature, at which carbon would then have no resistance, and beyond it a negative one; a law by which this curve would approach the axis asymptotically would be far more probably correct.

The extension of any empirical law beyond the limits of the experimental data is, of course, always precarious, as it assumes not only that the law is the correct one for the determined part, but also that it continues to be the same. It would take no cognizance, for instance, of the physical pranks which iron plays at its recalescence point, or of the possible abrupt changes in metals at their melting points, or of the changes of carbon to graphite at high temperatures, etc. Exterpolated values are therefore at best only more or less probable, and should never be considered to be anything more. The only excuse for their use is that the actual measured values do not exist, but in such a case an empirical law may become very useful if its correctness is sufficiently probable.

The use of exterpolations is of importance in the present case on account of the great difficulties encountered in making accurate tests at high temperatures. The uncertainty of the correctness of the actual measurements at such ranges might, in fact, be nearly if not quite as great as that involved in exterpolations by means of general laws based on measurements taken at lower temperatures, at which they can be made with the necessary accuracy.

In the present paper an attempt will therefore be made to find general laws of sufficient probable correctness that one may feel

reasonably safe in exterpolating somewhat beyond the experimental determinations. This may at least serve as a useful temporary expedient until the actual determinations are made.

Experimental results. The writer's tests were made for carbon, graphite, iron and copper, and the temperatures were carried as high as the material permitted without alteration of its size and shape, that is, near to the melting points of the metals and near to the oxidation points of the graphite and carbon. Beyond these points special precautions must be taken to keep the molten metal in its original shape, to avoid vaporizing, to prevent rupture by the "pinch" effect, and to keep the test-piece absolutely free from contact with gases (especially oxygen and CO_2), or with refractory materials which unite with the material under test. These necessary precautions increase very greatly the difficulties of making the test, which even at lower temperatures is tedious, as all tests involving flows of heat necessarily are.

The method used was the one devised by the writer for this purpose and described in a paper on "A New Method of Measuring Mean Thermal and Electrical Conductivities of Furnace Electrodes."[2] The execution of the test is described in another paper ("Determinations of the Constants of Materials for Furnace Electrodes"), in which the results are also given, to be read at this meeting.

It may be said briefly here that the tests were carried out with care and that the results are believed to be reliable; they are probably even more accurate than is required for their usual practical applications. The reason why such care was taken was that the data was new and could therefore not be checked approximately by comparisons with other carefully measured constants; moreover it was found soon after the start that either our former data (what little there was of it) or the deductions from the present tests were quite wrong; the writer therefore wished to be quite sure that there were no errors in his determinations. Later on in the tests it was also hoped that it might perhaps be possible to deduce some general laws from them, if such laws exist, hence the last series, namely that with copper, was made more carefully and over a wider range.

These tests give the proper mean values for the two conduc-

[2] These Transactions, **16**, 317.

tivities to be used in the writer's formulas given in the earlier paper; and as they were determined for each of a number of ranges, they embody in a very simple way and very effectively all the necessary corrections for different temperatures which had given rise to such a long academic discussion of the previous paper; altho this was fully described in that paper, it was entirely overlooked by those who laid such great stress on these academic minutia.

This mean value is that which the electrode has as a whole, and is therefore that of an equivalent electrode whose conductivities are the same from end to end, and which therefore would operate exactly like the original one as far as the end results are concerned. The distribution of the heat in the interior would, however, be different in the two, and for investigating that feature the variations of the conductivities with the temperature must be considered; but not when the electrode as a whole is concerned. Brief discussions of the general effects of this difference in the interior heat distribution are given in recent articles[3] by the writer.

The error due to the leakage of electrode heat to or from the walls is thought to be too small to need any serious consideration in practice. The usual electrodes have a thermal conductivity which is so enormously greater than that of the usual heat insulating materials that the quantity of heat which would leave them to enter the walls would seem to be relatively exceedingly small even if there existed a considerable difference of temperature between them at neighboring parts; but as the temperature gradients are always approximately the same, no such great difference in temperature is likely to exist and there is a very high thermal resistance at the contact surfaces. Besides this the normal flow of heat out of the electrode is, or ought to be, about twice as great as would flow by conduction alone, hence this small relative loss is thereby again halved. Moreover, this leakage, however small it is, would generally be from the electrode to the wall, and in the test a slight leakage is that direction existed; hence the leakage in the test and that in the actual cases are generally in the same direction, therefore the error, whatever

[3] "Properties and Behavior of Furnace Electrodes," Metallurg. and Chem. Eng., March, 1910, p. 128. Another on "Chilling or Heating Action of Furnace Electrodes vs. Least Electrode Loss," ibid. April, 1910, p. 188.

it may be, is in part and perhaps entirely taken care of. In the writer's opinion the discussion of the subject of this small leakage is therefore of academic rather than of practical interest.

The experimental results of these tests, of course, refer to electrodes which are proportioned and operated under the conditions of no loss of furnace heat and (approximately at least, if not exactly) of the minimum total loss, as specified in the previous paper.

The measured data in this test are the current, the drop of potential, the two temperatures, and the dimensions of the electrode; they are given in Table I, in which they have been reduced to a common basis. All the other results are deduced from these. The product of the volts and amperes gives the total heat flow in watts, and their quotient gives the resistance.

Table I.

Measured Data.

The currents have all been reduced to those for a uniform diameter of 5/8 inch (1.588 cm.) and a length of 8 inches (20.32 cm.). The outside terminal temperatures have all been reduced to 100° C. The volts refer to a single electrode.

Material	Amperes, I	Volts, E	Drop in Temperature, T (centigrade)
Carbon	20.9	0.904	260.
"	41.0	1.607	651.
"	48.0	1.855	842.
Graphite	96.4	0.830	290.
"	118.2	1.000	446.
"	137.3	1.130	620.
"	151.5	1.276	814.
Iron	372.4	0.1435	298.
"	377.8	0.3735	627.
"	380.1	0.3206	812.
"	414.5	0.4318	1145.
Copper	1785.	0.0463	97.
"	2087.	0.0639	169.
"	2351.	0.0875	271.
"	2596.	0.1253	441.
"	2730.	0.1894	737.

New physical properties. It was shown in the writer's earlier papers that, contrary to our former deep-rooted ideas, neither the thermal conductivity nor the electrical resistivity alone are true measures of the good or bad qualities of electrode materials,

just as neither volts nor amperes alone are measures of power or resistance. It was there shown that the two true measures of the qualities of materials for electrodes are the product and the quotient of those two physical properties, just as the product and the quotient of volts and amperes are the true measures of power and resistance. For calculating electrodes it is therefore not only unnecessary to know either of these two conductivities or their temperature coefficients, but it is even far simpler to abandon them entirely and use those two new quantities instead, just as we use watts and ohms in place of the product and quotient of two other quantities.

These new quantities are both true physical properties, quite as much so as conductivities, specific gravities, specific heats, etc. They have no names; one is the product (rk) of the electrical resistivity (r) and the thermal conductivity (k) (or the quotient of the thermal by the electrical conductivity). This quantity is a true measure of that property of an electrode material which determines the loss of power. The other is the quotient (r/k) of the electrical resistivity (r) by the thermal conductivity (k) (or the reciprocal of the product of the two conductivities). This quantity is a true measure of that property of an electrode material which determines its proportions. Hence the smaller rk is the less the power loss, and the smaller r/k the smaller the section of the electrode relatively to its length.

It is better, therefore, to investigate these two new properties rather than those formerly used. The new ones are determined directly from the tests, more directly even than the older ones; the latter are easily determined from the former if desired, and for some minor purposes they are of use, as, for instance, for investigating the distribution of the heat between the two ends of an electrode.

But even these two new physical properties may, in the writer's method, be eliminated from most calculations in practice by calculating once for all the values of certain derivatives of them which are constant for each given range of temperature, and tabulating them. The calculations in practice then become the ideal of simplicity, consisting merely of a simple multiplication, like those based on Ohm's, Faraday's and Joule's law, which in many cases could be done mentally.

This has been described in the A. I. E. E. paper, above referred to, on "The Proportioning of Electrodes for Furnaces." Briefly it is as follows. In the writer's original analysis of the laws, it was shown[4] that

$$E = \sqrt{2krT} \qquad (1)$$

in which E is the drop of potential in volts between the two ends of an electrode operating normally under the specified conditions; T is the drop in temperature in centigrade degrees between the two ends (not the furnace temperature); r is the mean electrical resistivity in ohm, cubic inch units, for that range of temperatures; and k the corresponding mean thermal conductivity in watt, cubic inch units for that range; or the two latter may equally well be in cubic centimeter units. The thermal conductivity is here represented in terms of electrical units, watts, as this greatly simplifies calculations; that this is strictly correct was shown elsewhere by the writer; the attempted improvement on this unit by others who have modified it to the cumbersome form "watt-seconds per second" is entirely unnecessary and complicates rather than simplifies matters.

This voltage, it was pointed out, is independent of the current, provided only that it is the normal one. Hence this quantity E is a true property of the material, for each temperature, and therefore has a fixed value for each temperature range; its values may therefore be tabulated, as the temperature of a furnace is always one of the specified data. This has the advantage of embodying in these tabulated values, the temperature coefficients of that new physical property kr, besides avoiding the square root calculation. Moreover it has the further great advantage that when the correct mean values of the constants are determined by the method proposed by the writer, these correct values of E are measured directly, and may therefore be tabulated just as they are measured without any further deductions.

Now the loss X in an electrode in watts, operating under the given conditions, was shown[5] to be simply

$$X = E\,I \qquad (2)$$

in which I is the normal current in amperes. Hence when these values of E are tabulated for different temperatures, the remain-

[4] These Transactions, **16**, 275, formula (4).
[5] These Transactions, **16**, 272, formula (2).

ing calculation of the total loss is reduced to the acme of simplicity.

It will be seen that this quantity E in volts, also represents the "watts per ampere" and as this name gives a better conception of the physical meaning of this quantity, it has been suggested in the writer's other papers to call it so.

This quantity E is therefore by itself the constant for the true measure of the loss of power when operating under normal conditions.

The second new quantity which can also be tabulated in the same way and with the same advantages, may be called the section per ampere and per inch length for any given range of temperature, and which therefore, by merely multiplying by the current and the length of the electrode, gives the correct cross section in square inches. This is also as true a specific quantity for each temperature range, as the specific resistance for any particular temperature is.

Altho it is not customary to use specific sections, there is no good reason for not doing so, and there are many advantages in the present case.

This quantity is derived from the analytic deductions[6] and is equal to

$$S' = 1\sqrt{r/2kT} \qquad (3)$$

when the current and the length are both made unity. The units are the same as above stated, S' being in square inches or square centimeters, depending upon the units used for r and k.

As with the quantity E, these values of S' may be tabulated for each of various temperature ranges, thereby again eliminating (by inclusion in the constants) all calculations concerning the temperature coefficients and also the square root calculations, thus leaving nothing further to do than to multiply this value of S' from the table, by the current and the length to get the final cross section in square inches. That is, the desired cross section is

$$S = S' I L \qquad (4)$$

When the writer's experimental method is used to determine these constants, these values of S' are calculated very readily and

[6] These Transactions, 16, 277, formula (6).

directly by dividing the cross section of the electrode under test by the product of its length and the observed current, because

$$S' = S/IL \qquad (5)$$

This quantity S' is therefore by itself the constant for the true measure of the proportions of an electrode when it is to be operated under normal conditions.

Empirical laws. The above shows that if it is possible to find some empirical laws for the values of these two simple and determining quantities E and S', which together are all that is required for calculating an electrode, it would be greatly preferable to the former way of finding not only the laws of variation of the conductivities with the temperature but also a method of calculating the true mean value from them, and then introducing these quantities in the original formulas of the analysis. Such laws for the conductivity variations have not yet been found and would be tedious to determine; the present method makes this unnecessary. Even if they were known, it would still have to be determined by intricate calculations what the true mean values would be for an electrode, if the corrections due to these variations are important enough to be taken into consideration. This also is now made unnecessary by the present method, as these variations are all included in the values found by direct measurement.

The present efforts to find empirical laws were therefore directed to these two quantities, the desire being to find if possible some one general law for each, which applies to all four of the materials tested, namely carbon, graphite, iron and copper, differing only in the numerical constants. If such laws exist for these widely differing materials, the probability that they are general and not merely accidental, becomes very strong.

An examination of the curves for all the various and numerous physical properties and their derivatives, also showed that these two quantities were moreover apparently the best ones to use in searching for such laws.

Power loss. Plotting the values of E in Fig. 1, as determined from the tests, and drawing approximate curves thru them, it will be seen that these curves all have a strong family resemblance. From the nature of the test they must all pass thru the common

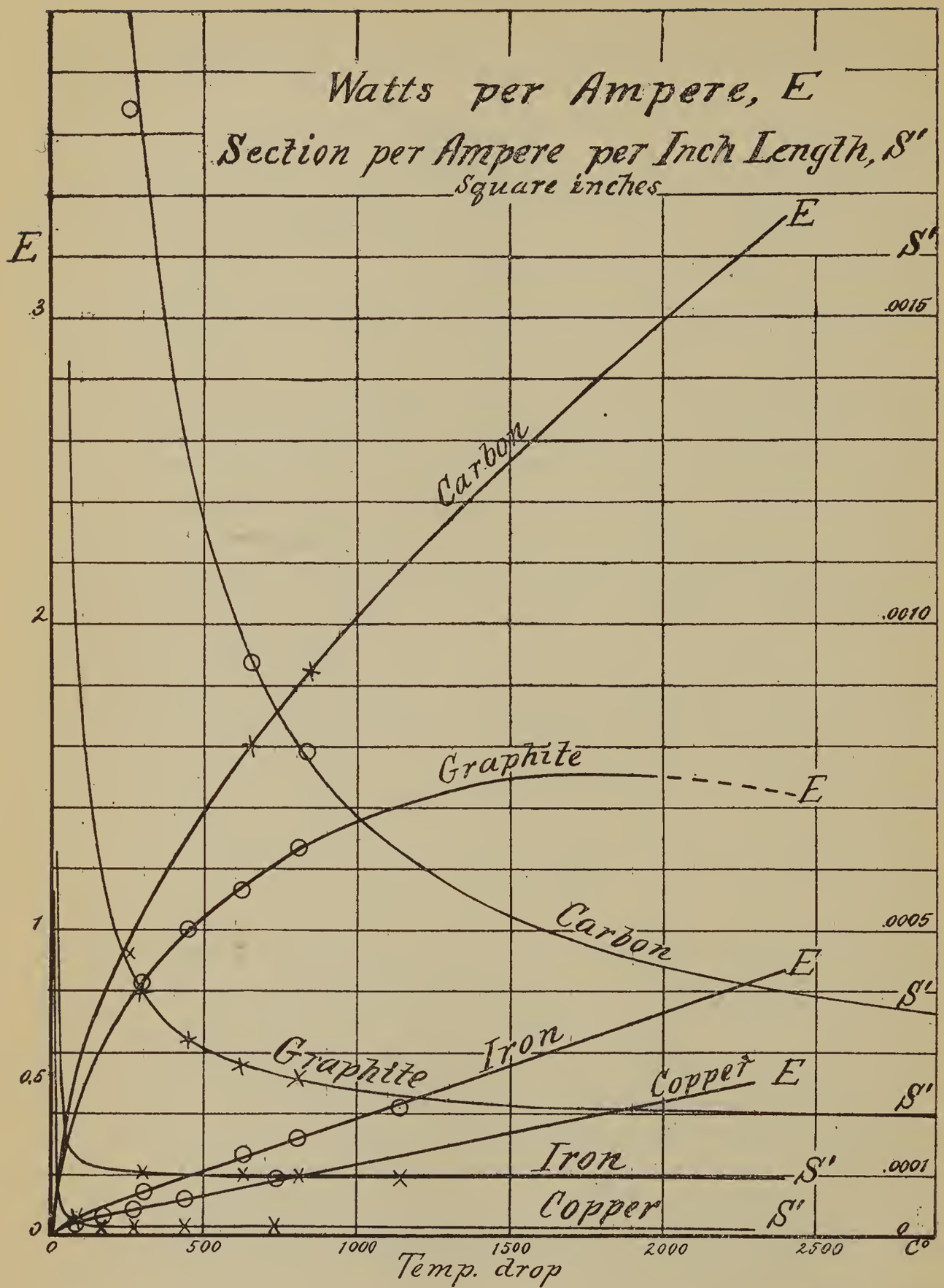


FIG. 1. Constants for Losses and Sizes; same scale.

zero of both axes, which gives an additional and very important point for each one. Moreover they all diminish in their inclination to the horizontal, tending apparently to become straight lines,

either parallel to the axis of x or inclined to it. Hence this suggests the hyperbola, of which the parabola and ellipse may be said to be special cases.

The general equation for such a hyperbola is

$$y^2 = ax + bx^2 \qquad (6)$$

which in the present case would be

$$E^2 = aT + bT^2 \qquad (7)$$

in which a and b are the desired constants, and T is the drop of temperature (not the furnace temperature).

Applying this law to the observed results gave such a close agreement for the more extended series, copper, and such a good agreement for all the materials, that it would be extremely improbable that it is merely accidental or far wrong. The curves here drawn follow this law, and in Table II the differences between the observed and the calculated values are given.

Table II.

Differences between Calculated and Observed Results in Percent.

T is drop of temperature, not furnace temperature.

	T	E	I	S′
Copper	97.	—1.5	—2.6	+2.9
"	169.	+0.2	+0.9	—0.8
"	271.	+0.1	+0.6	—0.5
"	441.	—0.5	—1.1	+1.3
"	737.	—1.6	—0.6	+0.7
Iron	298.	+1.6	—2.4	+2.4
"	627.	—4.2	+0.6	—0.6
"	812.	+1.6	+1.0	—0.9
"	1145.	+1.9	—6.5	+7.0
Graphite	290.	—0.5	—1.2	+1.4
"	446.	+0.1	+0.7	—0.6
"	620.	+1.6	—0.4	+0.5
"	814.	—0.3	—0.6	+0.8
Carbon	260.	+10.0	—10.7	+12.1
"	651.	+0.1	—0.8	+0.8
"	842.	—0.5	+3.3	—3.3

For causes explained in the description of the tests in another paper, the iron and graphite rods had been slightly injured prior to the highest temperature test the results of which are therefore less reliable; less care was taken at the low temperature values,

especially of carbon; the most reliable results are those for copper, and fortunately this series also contains the largest number of points, namely six including the zero. The laws were therefore tested more particularly on the results for this material. Unfortunately several points in the series for carbon had to be thrown out while the test was made, hence the agreement is not so surprising, as there are less points. Attention is also called here to the recalescence point in iron, about 700° C., at which physical irregularities are known to occur, in which the properties here involved probably also take part, hence close agreement cannot be expected for iron in the neighborhood of this point.

For graphite the second coefficient b was found to be slightly negative, thus making that curve an ellipse, which means that the curve tends to bend downward again slightly at the higher temperatures as shown. This would mean that for graphite the loss would diminish again slightly at the higher temperatures. This can be decided only by further experiments. Such an ellipse, if prolonged, would give a zero value, which of course is an impossible one, hence the constants cannot be exactly correct. A more extended investigation would probably show it to be a parabola, or very nearly so. The present constants should not be used for very high temperatures; for such cases the graphical extension of the curves would probably be a better guide.

It is interesting to notice from this curve that the loss of power increases much less rapidly for the higher temperatures for graphite than for any other material and may perhaps become virtually a constant. Graphite is the only one of the four materials in which the mean electrical resistivity and mean thermal conductivity both fall with the rise of temperature (see figs. 3 and 4); this may explain the peculiar nature of this curve.

Table III.

E. Watts per ampere.

$E^2 = aT + bT^2$ (Watts $= EI$)

	a	b
Carbon	0.003.73	0.000,000,366
Graphite	0.002,56	—0.000,000,710
Iron	0.000,036,9	0.000,000,116
Copper	0.000,017,6	0.000,000,039,9

The values of the constants a and b for these curves are given in Table III. The curves themselves represent the relative and absolute losses for the different materials, as they are drawn to the same scale for all. That for carbon is very nearly a parabola. A set of values of E calculated from these laws is given in Table IV.

TABLE IV.

Loss E.

Watts per ampere. Watts = E × current.

Furnace Temperature. C°	Furnace Temperature. F°	Drop of Temperature T. C°	Carbon.	Graphite.	Iron.	Copper.
400	752	300	1.07	0.84	0.146	0.094
600	1112	500	1.40	1.05	0.218	0.137
800	1472	700	1.67	1.20	0.287	0.179
1000	1832	900	1.91	1.32	0.356	0.219
1200	2192	1100	2.13	1.40	0.425	0.260
1400	2552	1300	2.34	1.46	0.493	0.301
1600	2912	1500	2.53	1.50	0.562	0.341
1800	3272	1700	2.72	1.52	0.630	0.381
2000	3632	1900	2.90	1.52	0.698	0.421

Practical deductions from these curves and from other results of these tests are given in the A. I. E. E. paper above referred to.

Cross section. The curves for S' are shown in fig. 1. They also have a very strong family resemblance, tho their relationship is not so easily found. The reciprocals are the same as the curves for the current, shown in fig. 2, which are certainly neither hyperbolas, parabolas nor curves of that class; hence it will not help matters to use their reciprocal values.

It will be noticed that they are all asymptotic to the y axis, which must necessarily be the case, and that while they also approach the axis of x asymptotically, they approach it at entirely different rates, and rather seem to tend to become asymptotic to a line parallel to x. This is shown more strikingly by their reciprocal values, fig. 2, in which this would mean that the lines tended to become horizontal, which is shown so very decidedly for iron; the more accurate results for copper tend also to give a curve of this same peculiar course.

Whether this is strictly true or not does not matter because it is so nearly so that it would make but a small difference in the actual values to assume it to be so; the chief feature is that these lines tend to follow such a law and would not be likely to be radically different; moreover this law gives no impossible or absurd values at far-distant exterpolated points, but it cannot, of course, be expected to give reliable values at low temperatures where a very slight error in the constants makes a very large difference in the results. In engineering work it is never required to use these formulas at those low temperatures.

A curve which follows such a law has the form

$$y = m + n/x \qquad (8)$$

hence in this case, T being again the drop and not the furnace temperature,

$$S' = m + n/T \qquad (9)$$

Trying this on the experimental values again shows a very good agreement, especially for the more accurate determinations of copper. The agreement is quite as good as for the E curves. It is therefore not likely that it is merely accidental or far wrong.

Table V.

S'. Section in square inches per ampere per inch length.
S'. Section in square centimeters per ampere per centimeter length.

$$S' = m + n/T$$
$$(S = S'IL)$$

	Inches		Centimeters	
	m	n	m	n
Carbon	0.000,200	0.483	0.000,508	1.23
Graphite	0.000,173	0.066,5	0.000,440	0.169
Iron	0.000,096,7	0.002,62	0.000,246	0.006,66
Copper	0.000,012,9	0.000,888	0.000,032,9	0.002,26

The curves here drawn follow this law; the values of the constants m and n are given in Table V; and Table II gives the differences between the observed and the calculated values. The reasons why a closer agreement was not to be expected for certain points, were given above. Graphite now shows no irregularity. A set of values for S' calculated from these laws is given in Table VI.

TABLE VI. *Cross Section. S'*

Section = S' × current × length.

Temperatures			Section in square inches per ampere per inch length				Section in sq. cm. per ampere per cm. length			
Furnace		Drop T								
C°	F°	C°	Carbon	Graphite	Iron	Copper	Carbon	Graphite	Iron	Copper
400	752	300	0.00181	0.00040	0 000105	0.000016	0.00460	0.00100	0.000268	0.000040
600	1112	500	0.00116	0.00031	0.000102	0.000015	0.00296	0.00078	0.000259	0.000037
800	1472	700	0.00089	0.00027	0.000100	0.000014	0.00226	0.00068	0.000255	0.000036
1000	1832	900	0.00074	0.00025	0.000100	0.000014	0.00187	0.00063	0.000253	0.000035
1200	2192	1100	0.00064	0.00023	0.000099	0.000014	0.00162	0.00059	0.000252	0.000035
1400	2552	1300	0.00057	0.00022	0.000099	0.000014	0.00145	0.00057	0.000251	0.000035
1600	2912	1500	0.00052	0.00022	0.000098	0.000013	0.00132	0.00055	0.000250	0.000034
1800	3272	1700	0.00048	0.00021	0.000098	0.000013	0.00123	0.00054	0.000249	0.000034
2000	3632	1900	0.00045	0.00021	0.000098	0.000013	0.00115	0.00053	0.000249	0.000034
2500	4532	2400	0.00040	0.00020			0.00102	0.00051		
3000	5432	2900	0.00037	0.00020			0.00093	0.00050		

TABLE VIII. *Current. I'*

Amperes = I' × section ÷ length.

Temperatures			Current for one inch length per sq. inch section				Current for one cm. length per sq. cm. length			
Furnace		Drop T								
C°	F°	C°	Carbon	Graphite	Iron	Copper	Carbon	Graphite	Iron	Copper
400	752	300	552.	2530.	9480.	62900.	217.	996.	3740.	24800.
600	1112	500	858.	3270.	9800.	67900.	338.	1290.	3860.	26700.
800	1472	700	1120.	3730.	9950.	70300.	442.	1470.	3920.	27700.
1000	1832	900	1360.	4060.	10000.	71800.	532.	1600.	3950.	28300.
1200	2192	1100	1570.	4280.	10100.	72800.	616.	1690.	3970.	28700.
1400	2552	1300	1750.	4460.	10100.	73400.	690.	1760.	3980.	28900.
1600	2912	1500	1920.	4600.	10200.	73900.	754.	1810.	4000.	29100.
1800	3272	1700	2070.	4720.	10200.	74300.	814.	1860.	4010.	29300.
2000	3632	1900	2200.	4800.	10200.	74600.	866.	1890.	4010.	29400.
2500	4532	2400	2490.	4970.			980.	1960.		
3000	5432	2900	2730.	5100.			1080.	2010.		

This law means that the proper section becomes smaller as the temperature increases, but less and less rapidly, and at the higher temperatures it is practically constant and nearly equal to the value m. This constant section however is quite different for different materials. There seems to be a reason why this should be so. It is very certain that the section becomes smaller the higher the temperature; but one end is always cold, and the

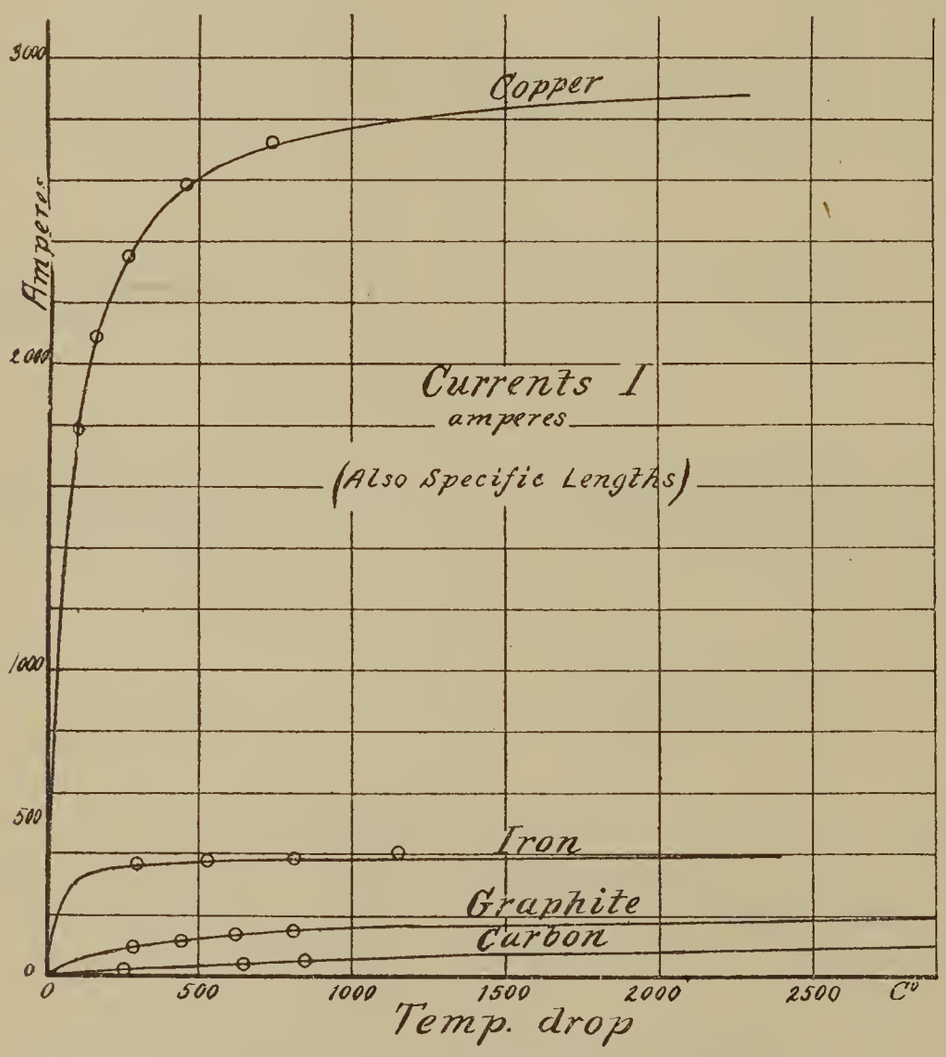


FIG. 2. Currents and Lengths.

proper mean value of the section depends quite as much on the values of the physical constants at the cold end which are constant; hence for the higher temperatures these seem to predominate. If this is the case, the constant m, which physically represents the section for an infinite temperature, may be some function of the physical constants at the low temperature; if so, it could be determined accurately at low temperatures, leaving only n to be determined at the more troublesome high temperatures.

The curve for iron shows that this approximately constant section is reached at quite moderate temperatures, which means that for iron electrodes it does not matter much what the furnace temperature is, the section is practically the same, or in other words, the section is nearly independent of the temperature. In all of them the section becomes more and more independent of the temperature the greater the heat, which is a useful property to be remembered.

Current. The reciprocals of these curves for S' can be shown to be those for the currents, hence it may be of interest to examine these too. They are drawn in fig. 2. These curves represent the current which will heat the hot end of the particular electrode under test, to the furnace temperatures.

The above law for these currents then becomes

$$I = \frac{pT}{q + T} \cdot \frac{S}{L} = \frac{p}{1 + q/T} \cdot \frac{S}{L} \qquad (10)$$

This current is of course not a specific quantity like E and S', as it will depend on the actual size of the particular electrode, that is on S and L. There is no reason, however, why in this case a specific quantity may not be used also, if there is any advantage in doing so. In most cases in practice the current is specified and is therefore not one of those quantities which is to be calculated, hence there is less need for such a formula. But it may at times be of use to find what current is the proper one to use in existing electrodes.

If such a specific current is represented by I' then

$$I' = \frac{pT}{q + T} = \frac{p}{1 + q/T} \qquad (11)$$

which values are readily calculated from the measured results of the test and from the preceding formula (10), by multiplying the observed currents I for each temperature, by L/S, which reduces the current to that for an inch length and an inch section. Knowing these currents and the temperatures, the constants p and q are readily determined, if they are wanted. They are given in Table VII. The tabulated values for I' are given in Table VIII.

TABLE VII.

I'. Current for one inch length per square inch section.
I'. Current for one centimeter length per square centimeter section.

$$I' = p/(1 + q/T)$$
$$(I = I'S/L)$$

	Inches		Centimeters	
	p	q	p	q
Carbon	5,000.	2,415.	1,968.	2,415.
Graphite	5,768.	384.	2,271.	384.
Iron	10,340.	27.1	4,071.	27.1
Copper	77,240.	68.6	30,410.	68.6

Having such a tabulated set of values of I', the actual current for any particular case is readily calculated from the simple formula

$$I = I' S/L \qquad (12)$$

that is, by multiplying the constant I' for the particular temperature by the section and dividing by the length.

The curves here drawn are plotted according to this law.

This law will be seen to signify that the current tends to becomes a constant equal to p at higher temperatures; rapidly so when q is small, as it is for iron, and more gradually when it is large, as it is for carbon. This in turn means that for the higher temperatures (and with iron, for even quite moderate ones) a given current in an electrode will produce practically any temperature without any material differences in the size of the electrodes.

In other words, at the higher temperatures the electrodes become more and more sensitive to an increase of current. This is especially noticeable in the curve for iron, which material is extremely sensitive; it was because the writer had not yet realized this while the tests were being made, that an increase of current intended to give a slightly higher temperature, at once melted and perhaps even volatilized the tips of the electrodes; it is this accident which made the higher temperature value less accurate. Fortunately it seemed to affect only the very tip end of the electrode. The Thomson effect, which is very strong in iron, may perhaps have taken part in this peculiar behavior.

This sensitiveness is much less for graphite and still less for carbon. But on the other hand these high temperatures are

worse for carbon for the reason that the heat in carbon electrodes is crowded to the cold end,[7] to use somewhat unscientific but more easily understood terms; hence an increase of current is very apt to destroy the walls. With iron on the other hand the heat is crowded back to the hot end where it belongs; hence any such excesses of temperature will be less apt to do harm, and the heat will tend to flow into the nearby furnace. On account of the flatness of this current curve, iron electrodes have a strong tendency to regulate for a constant current. This is no doubt due to the rapidly rising electrical resistivity combined with a falling thermal conductivity, both of which tend to force the heat back to the hot end, as was explained in the article above referred to. With iron, an excessive current seems to concentrate its effect at the tip of the electrode near the furnace. But with carbon the action is the wrong way, namely toward the cold end. Graphite is somewhere between the two in this feature, the indications being strong that it is more like iron than like carbon, as was described elsewhere.

Length. Altho these current curves in fig. 2 are of less interest in practice because the current is generally specified and therefore is not to be calculated, it will be seen that with a mere change of scale values they also represent the lengths of electrodes, for one ampere, when the sections are made unity. That is, just as the specific section S' at any particular temperature, is the section for one ampere and one inch length, so these current curves represent what might similarly be termed the specific length for one ampere and one inch section, and may be represented by L'. The two are quite analogous and either may be used in practice. As the length is generally determined by other considerations, such as the thickness of the walls, etc., the writer has selected S' as the one which is to be determined by the designer to meet the specified conditions. The formulas and constants for L' can readily be deduced from those given, and it is therefore unnecessary to add them here.

Some general conclusions of interest may, however, be drawn from the curves for the lengths. Assuming the curves of fig. 2 to represent these specific lengths, it is seen that at the higher

[7] "Properties and Behavior of Furnace Electrodes," Metallurg. and Chem. Eng., March, 1910, p. 128.

temperatures the length of an electrode for a unit section and for one ampere, tends to become a constant; that is, the length tends to become more and more independent of the temperature. This is also worth remembering. For iron this independence

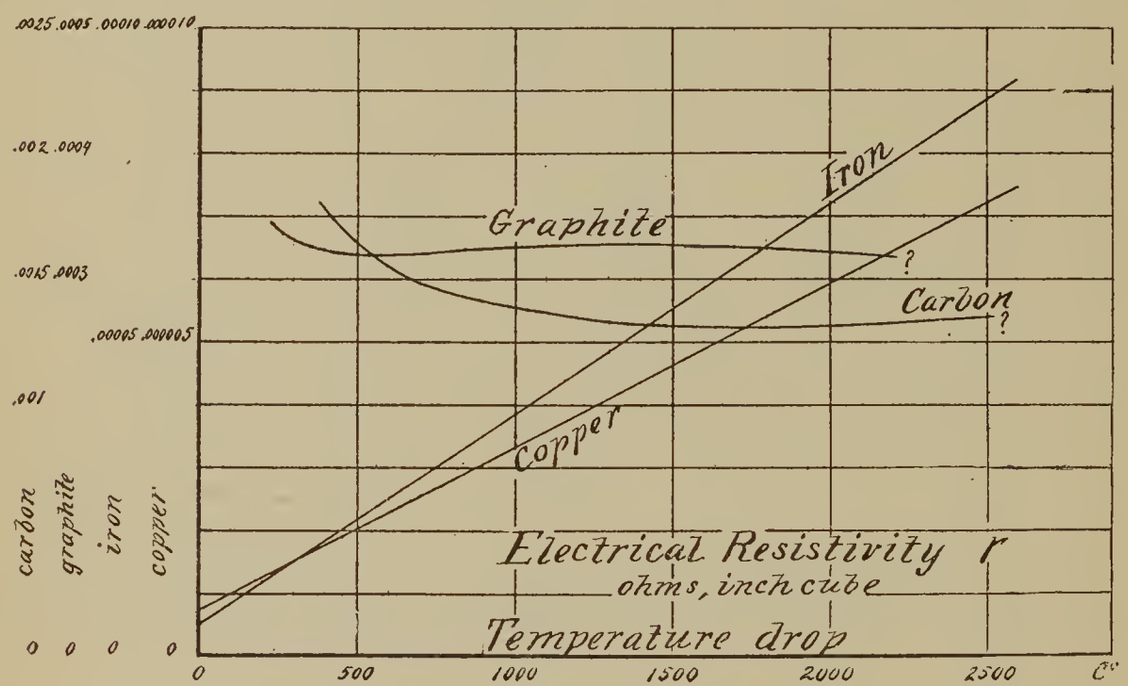


FIG. 3. "Electrode Mean" Electrical Resistivities *r*.

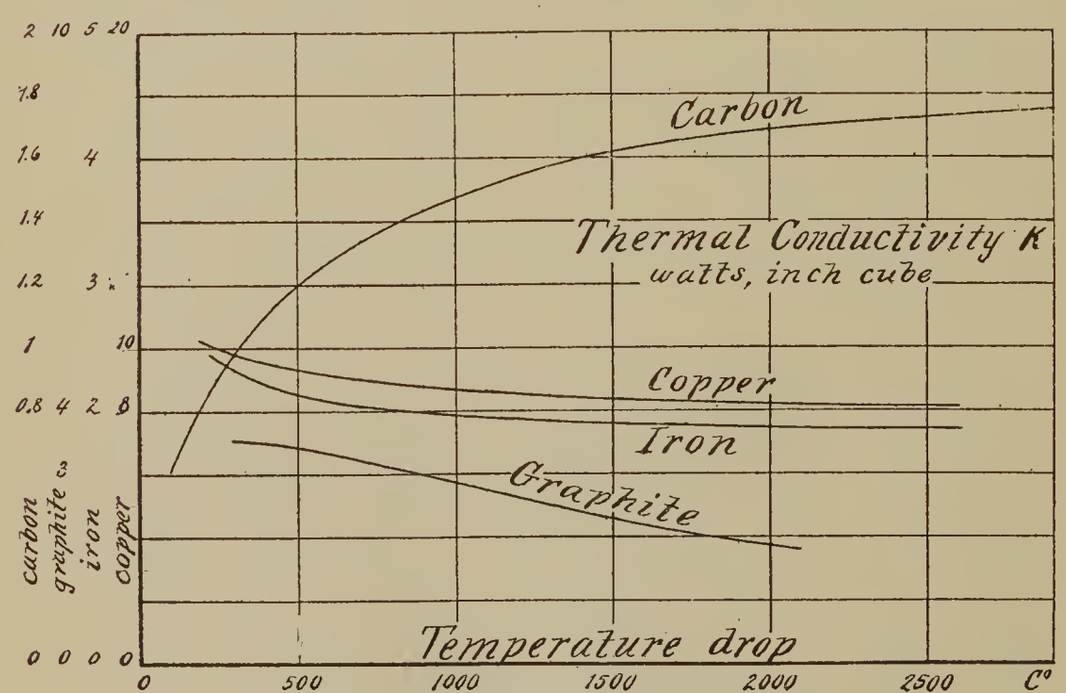


FIG 4. "Electrode Mean" Thermal Conductivities *k*.

begins at quite moderate temperatures; for copper about at the fusing point; while for graphite, and especially for carbon, it would probably not be reached by temperatures used in practice; still, even with the latter materials it may often be of value to

know that for the higher temperatures the proper length becomes less and less dependent on the temperatures.

This also signifies that the proper length is more definitely established for the higher temperatures, and that therefore a relatively small increase of the current above the normal will cause a very decided increase in temperature. This has already been referred to in discussing the current curves. It means that greater care should be taken in determining the length (the cross section being fixed) when the temperatures are high. If too long, the current will tend to burn the electrode down to its proper length; this would do no harm with iron electrodes, as it would merely fuse off a little more from the hot end; for carbon, however, the high temperatures would be carried deep into the walls, nearer to the cold end, thereby tending to destroy the walls. With carbon therefore it seems to be very much worse to make them too long than too short. This is unfortunate, as carbon electrodes for large currents are necessarily quite short, relatively to the section, and to make them still shorter makes it still more difficult to give them practicable proportions.

Conductivities. Many other interesting and useful deductions can be made from these curves; quite a number of these have been described by the writer in other papers and articles. For some of these deductions it is desirable to know the mean values of the two conductivities, hence they have been added here in figs. 3 and 4. The values here given are calculated from the empirical laws deduced above; and as the original data agrees so closely with these laws, the values determined directly from the experimental data will also agree closely except, of course, at the low temperature ranges, at which, however, they are of no interest in furnace work. The direct deductions from the experimental data are given in the curves of the A. I. E. E. paper above referred to.

The electrical resistivity is readily calculated from the quantities E and S' by the simple formula

$$r = E \times S' \qquad (13)$$

The thermal conductivity is readily calculated from the formula

$$k = \frac{E}{2\,S'\,T} \qquad (14)$$

It will be seen from fig. 3 that for copper and iron r follows practically a straight line law, the numerical values for which law are given below. Carbon falls and then seems to become

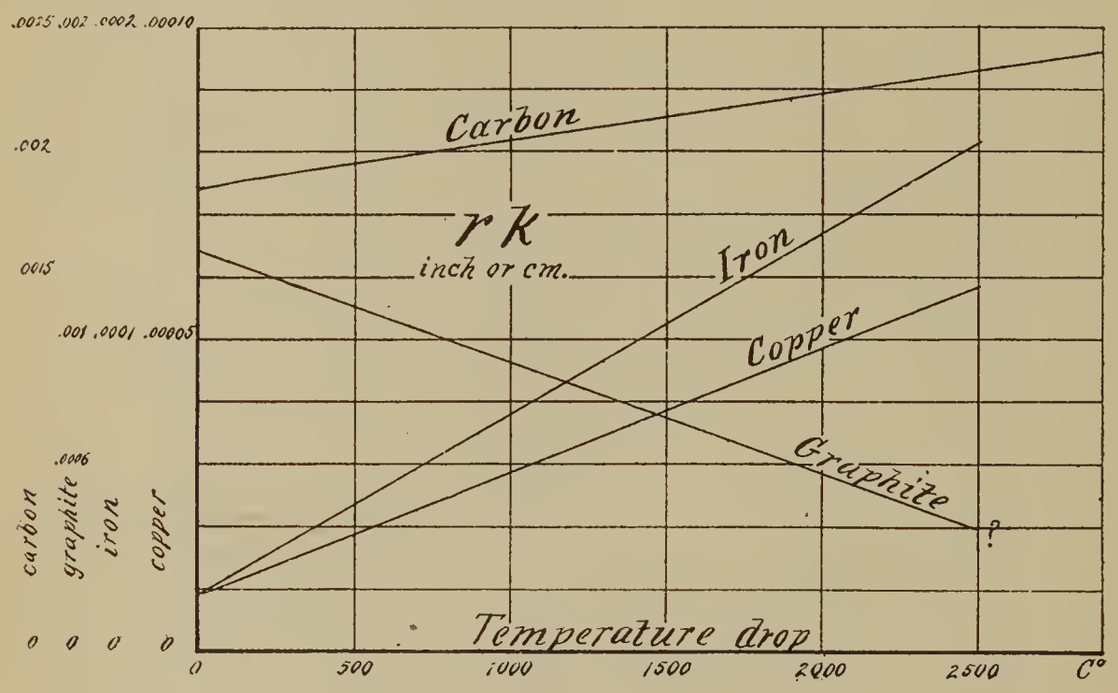


FIG. 5. Ratios of Conductivities.

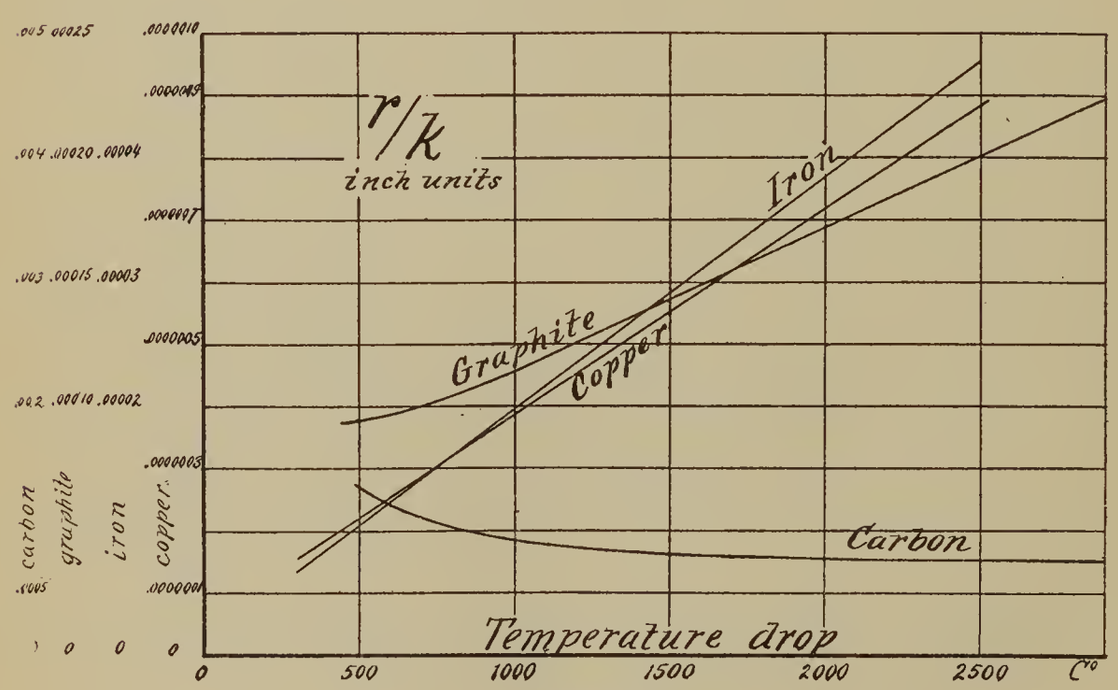


FIG. 6. Product of Resistivities.

nearly constant. At the higher temperature ranges it seems to tend to rise again, but the numerical constants for carbon in these equations are unfortunately not as reliable as those for the other materials, as there were fewer points, hence the equation

may be said to fit only loosely. Too much reliance should therefore not be placed in the more distant exterpolated values for carbon.

The slight hump in the graphite curve at 1,100° to 1,500° is interesting, if it can be relied upon. It has been found by others that the resistivity of graphite at first falls and then rises again, at which turning point graphite may be said to begin to take the property of the metals. If so, it seems that there should be such a rise in this curve also. The subsequent very slight fall may be due to an inaccuracy in the constants here used.

Further attempts to get still better fitting constants for the formulas for graphite and carbon from these tests, would probably meet with some success. It is tedious, however, and the writer considered it would be better to repeat the tests for these two materials with the present object in view, and obtain more points and more accurate values.

It should not be forgotten that all the constants given in this paper are those for the mean values under electrode conditions for the given *ranges* of temperature, and not those *at* those temperatures.

The values of the two new physical properties *rk* and *r/k,* are also readily calculated from the following self-evident formulas

$$rk = E^2/2T \qquad (15)$$

$$r/k = S'^2 \times 2T \qquad (16)$$

These values are given in figs. 5 and 6.

The temperature coefficients of these two quantities are also easily determined by means of the two empirical laws given above. It may be of interest to state that for the quantity *rk* the temperature variation is a straight line law, and for *r/k* it is approximately so for the higher temperatures, as will be shown below.

Physical conceptions. In dealing with such new physical quantities, or with old ones in a new dress, it is of interest and sometimes of value to understand their physical meanings.

E measured in volts, represents what might be called the specific loss in watts for any particular range of temperature; that is, the loss per ampere, as already explained. Altho correctly measured in volts, its real significance is better represented by the term "watts per ampere."

S' is the specific section (hence measured in units of areas) for any particular range of temperature, that is, the cross section required per ampere and per inch of length, in order that there shall be no flow of heat either way thru the furnace end.

I' is the specific current in amperes for any particular temperature range, that is, the current per square inch for each inch length, which will produce the condition of no flow of heat thru the furnace end.

The constant a in formula (7) represents the square of the electrode voltage when the drop in temperature is zero; this, of course, is not a physical reality as there could then be no flow of heat. It may therefore be said to be the square of the electrode voltage if there were no temperature correction to add. Or it may be said that $a + b$ is the square of the electrode voltage for one degree at 100°. The constant b may be said to be the temperature coefficient of the square of the electrode voltage.

The constant m in formula (9) represents the smallest possible section per ampere and per inch which any electrode of that material can have, that is, the one for an infinitely high temperature. The constant n may be said to be a kind of temperature coefficient, if the temperature could be imagined to be reckoned from infinity downwards instead of from zero upwards as is more usual. In other words, it is that factor which changes with the temperature, as distinguished from the constant factor m which is independent of the temperature.

The constant p in formula (11) is the maximum current per square inch for one inch length, which an electrode of that material can stand, that is, when the temperature is practically infinite. A higher current would produce excessive temperatures within the walls. The constant q in that formula is again a kind of temperature coefficient, being that factor which is affected by the temperature. It can be shown that p is always the reciprocal of m, while q is the quotient of n divided by m. The formulas (9) and (11) are therefore interlinked and embody the same relation.

The electrode voltage signifies the average volts (always a very small fraction of a volt) required for one degree of the range, to bring about the required condition of end temperature. It is a physical constant which is a measure of the loss, and when multi-

plied by the square root of the total temperature drop, gives E. By using E, therefore the electrode voltage need not enter. E may be said to be a summation or integration of the electrode voltages for the whole range.

The specific section is equal to S' reduced to one degree; it is also a physical constant and measures the size. S' may again be said to be a summation of the specific sections for the whole range.

The new quantity rk is of the nature of the square of a voltage divided by a temperature and as no such quantity seems to be known, it is difficult to form a conception. The simplest conception of it is that it is merely the ratio of the two conductivities, the thermal divided by the electrical. Hence this ratio is what determines the loss, as described in the writer's earlier papers. It is therefore the same whether the conductivities are given in inch or in centimeter units. It is a curious and interesting fact that the mean values of this quantity under electrode conditions seem to have a rectilinear temperature coefficient as shown above; this it seems would be necessarily so, if these empirical laws were rigidly correct.

The other new quantity r/k also seems to have no physical counterpart, and is best considered as the reciprocal of the product of the two conductivities (or the product of the two resistivities). It is therefore this product which determines the size of an electrode. Unlike its mate rk, its values are not independent of the linear units. The values in inch units must be multiplied by 6.452 (the number of square centimeters in one square inch) to reduce them to centimeter units. The electrode mean values of this quantity also seem to have a temperature coefficient which is generally rectilinear for the higher temperature, as shown above. The product itself instead of its reciprocal, could be used equally well, requiring but slight changes in the formula, and it might even be simpler to use it.

Other deductions. It will be seen that as E, S' and I' are all given in terms of temperature ranges in these empirical formulas (7), (9) and (11), it is possible to deduce relations between these quantities themselves by eliminating the temperature drop T from any two of them. Or they may be combined in other ways

because they have this connecting link in T. Such combinations should, however, be made with caution as it may lead to what might be called mathematical jugglery, because these equations are only empirical, and some of them are such as might give very incorrect results at very low temperature ranges for which they are not intended; this is due to the fact that for such extreme values a relatively small incorrectness in the constants may give rise to relatively large errors in the results. The equations are really correct only over the measured ranges and then only as far as they agree with these; beyond this in either direction they are only probably so.

The sensitiveness of the constants of some of these equations at the low temperatures suggests that perhaps for this reason it might be better to determine them at these low temperatures at which the tests involve less difficulties, and permit of greater accuracy.

Attention is here again called to the fact that thruout this paper T represents the drop of temperature in the electrode and not the furnace temperature, which latter is assumed to be 100° higher. This distinction is important if consistent results are expected.

The agreement between these general laws and the observed data is closer and more reliable for copper and iron, especially the former; this suggests that others who may be interested in further algebraic analyses, had better use these sets of values rather than those for graphite and carbon.

It may be of interest to notice that by mere changes of the scales, which of course does not change the relations, all the curves for S' may be made to superimpose. Hence the position which the various materials take on this one curve, if each is plotted for the same range of temperature, gives a quantitative relationship of the materials. This seems to show that carbon at exceedingly high temperatures would partake of the qualities of metals and that graphite is a partial step in that direction. Graphite may be said to bring back with it to the low temperatures, some of the qualities which carbon had at the high temperature at which it was changed into graphite, thus confirming similar deductions made by others. It suggests that perhaps if the temperatures at which graphite is made were carried still

higher, the resulting graphite might perhaps have properties still more allied to the metals, and if so, it would improve it for electrode purposes, even tho its thermal conductivity may thereby be still further increased. These and many other possibilities are suggested by the results of an investigation like the present one.

Temperature coefficients. The following formulas including the rectilinear temperature coefficients, are readily deduced from the above and may perhaps sometimes be of use. T is the drop of temperature. They of course refer to the electrode means; also to inch units. Their curves are shown in figs. 3, 5 and 6. Most of these are only approximate, and none of them are supposed to apply to low temperatures, as has already been explained.

r for carbon practically constant over 1,000°, about 0.0013.
r " graphite " " " " " 0.00033.
r " iron $= (500 + 3.33\ T)\ 10^{-8}$
r " copper $= (700 + 2.61\ T)\ 10^{-9}$
rk " carbon $= (18{,}500 + 1.90\ T)\ 10^{-7}$
rk " graphite $= (12{,}800 - 3.56\ T)\ 10^{-7}$
rk " iron $= (1{,}800 + 5.79\ T)\ 10^{-8}$
rk " copper $= (900 + 1.97\ T)\ 10^{-8}$
r/k " carbon above about 1,100° C. $= 0.00080$
r/k " graphite above about 800° C. $= (5{,}500 + 5.86\ T)\ 10^{-8}$
r/k " iron $= (100 + 1.88\ T)\ 10^{-8}$
r/k " copper $= (500 + 3.34\ T)\ 10^{-10}$

Conclusions. Owing to the close agreement of these empirical laws with the observed data, the writer has ventured to extend some of these curves to very high temperatures. This was done more for the purpose of studying these laws and their effects than to give the actual values for those temperatures. But until these high temperature values have been determined experimentally by some reliable method, these probable values may perhaps serve temporarily for approximate calculations of high temperature furnaces, especially as both the section and the length become more and more nearly constant. But in using the high temperature values given in these curves and tables, it should not be forgotten that they are only exterpolations and nothing more; all the original data are given in the writer's papers, so that

anyone can judge for himself how much or how little reliance he is willing to place on the exterpolations.

These having been the first extended series of determinations ever made of the complete set of physical constants under operating electrode conditions, some of the deductions from them made above were not known or even surmised when the tests were being conducted. If they had been, more attention would have been given to features which have since been shown to be important, and more temperature points would have been determined for carbon and graphite. Now that the general laws are known at least approximately, and the new method of testing has shown itself to be a satisfactory one, it is hoped that the subject may be deemed of sufficient interest and importance to warrant more extended researches on these same lines or on others suggested by them.

It is known, for instance, that carbon at very high temperatures changes into graphite; hence its electrode constants for those very high temperatures may be expected to approach those of graphite, but without ever reaching them because the cold end will always remain carbon, and the above investigations seem to show that at the higher temperatures the cold end constants predominate in importance.

Moreover graphite at even moderate temperatures seems to change some of its qualities from those of a non-metal (falling resistivity) to those of a metal. If this is the case it would not be unlikely that from that turning point to the higher temperatures the empirical laws for graphite may change and become more like those of the metals. These remarks are mere thoughts among others, which the above investigation suggests, and which anyone who may make a more extended investigation of the electrode properties of carbon and graphite, might with profit take into consideration.

Philadelphia, March 5, 1910.

DISCUSSION.

DR. A. E. KENNELLY *(Communicated)*: One of the many interesting facts brought out in Mr. Hering's paper is in connection with his Fig. 5, that the product rk is a straight-line function of the temperature drop. In other words, for each of the four substances tested, the product of electrode-mean electric resistivity and electrode-mean thermal conductivity, plots as a straight line against temperature-drop in the electrode.

Now $rk = k/g$, where g is the electrode-mean electric conductivity, or rk is the ratio of electrode-mean thermal conductivity to electrode-mean electric conductivity.

It is a recognized theoretical principle in physics, subject to certain reservations and exceptions, that the ratio of the thermal conductivity to the electric conductivity of a metal, at any given temperature, is proportional to the absolute temperature; or:

$$k_\theta / g_\theta = a\theta$$

where k_θ is the thermal conductivity at absolute temperature θ;
where g_θ is the electric conductivity at absolute temperature θ;
and a is a physical and numerical constant.

This is sometimes called the Wiedemann-Franz law.[1] It seems that this law of conductivities ratio has not yet been tested by physicists over a very wide range of temperature. Mr. Hering presents to us measurements covering a wide range of temperatures above 300° abs.; but he presents them in the form of electrode-mean values. These electrode-mean values are very useful for practical purposes. For theoretical purposes, however, they have to be reduced, as nearly as may be, to corresponding full-temperature values, in order to be capable of comparison with physical data from other sources.

If we try to construct, from Fig. 5 of Mr. Hering's paper, a corresponding diagram to abscissas of full temperature instead of temperature-drop, we should expect straight lines on the one diagram to exchange into straight lines on the other, but the inclinations of the various straight lines would be changed.

[1] Wiedemann's "Die Lehre von der Elektricität" (1882), Vol. I, p. 536.
Lorenz, Pogg. Ann. (1872), **147**, 429.
J. J. Thomson's "The Corpuscular Theory of Matter" (1907), p. 57.

According to the Wiedemann-Franz law, the lines of k/g or rk, for iron and copper on the new diagram, should be straight lines of a different slope, but both starting from absolute zero of temperature (—273° C.). In a general way, this agrees, although only to a first approximation, with the deductions from Fig. 5. That is, Mr. Hering's graphs in Fig. 5 are a first approximation to the Wiedemann-Franz law; and conversely, are explainable, to a first approximation, by that law.

The curious fact is that graphite and carbon also give straight lines in Fig. 5, although descending instead of ascending from a common zero point. They happen to start from a common origin, or intersection, at about —500° C. drop, in Fig. 5, nearly the same abscissa as that of copper.

Once granted that kr is a rectilinear function of the temperature-drop of the rectilinear form: $kr = a \pm b\,T$, where T is the temperature-drop, a and b being constants, it follows since E, the total voltage drop in the electrode, is:

$$\begin{aligned} E &= \int 2\,kr\,dT \\ &= \int 2a\,dT \pm 2b\,T^2 \\ &= \sqrt{a^1 T \pm b^1 T^2} \end{aligned}$$

where a^1 and b^1 are new constants, that E will be an ellipse or hyperbola according to the sign of b^1 (a parabola when $b = 0$), when E is plotted as ordinates to T as abscissas. In fact, Mr. Hering's Fig. 1 shows that E is a hyperbola for copper, and for iron, while it is an ellipse for graphite and almost a parabola for carbon.

We may say, then, that the Wiedemann-Franz law is the basis of the remarkable observed behavior of the electrode substances in Figs. 1 and 5.

This does not account directly for the fact that, according to Fig. 6, the product of the electrode-mean electric and thermal resistivities (r/k) for the metals iron and copper is a straight-line function of the temperature-drop. But if we add the remarkable and unexpected result given in Fig. 4, that the electrode-mean thermal conductivity of these two metals is roughly independent of the temperature-drop, *i. e.*, is constant, to a first approximation, then the Wiedemann-Franz law explains Fig. 6

also; because, if r_θ is the electric resistivity, and σ_θ the thermal resistivity, at any given absolute temperature θ, we have:

$$\sigma_\theta = 1/k_\theta \cong c$$

approximately a constant, by Fig. 4; also,

$$k_\theta \cdot r_\theta = a\theta$$

by Fig. 5, the Wiedemann-Franz law; therefore,

$$\frac{1}{k_\theta} \times k_\theta r_\theta = r_\theta = ac\theta$$

by Fig. 3; or, as is well known, approximately a straight-line function of θ; and

$$r_\theta \sigma_\theta = r_\theta / k_\theta = ac^2\theta$$

as in Fig. 6, becomes also a straight-line function of θ.

Consequently, restricting attention to the two metals, iron and copper, or neglecting the non-metallic conductors carbon and graphite, we may say that the interesting and important relations between the various properties of these metals set forth in Mr. Hering's paper may, to a first approximation, be accounted for (1) by the Wiedemann-Franz law, and (2) by the approximate constancy of the thermal conductivity and thermal resistivity of these metals throughout the range of temperature-drop covered by the observations.

Mr. H. W. Gillett *(Communicated)*:* In his paper on "Determination of the Constants," Mr. Hering assumes that a carbon or graphite rod of uniform cross-section embedded in a heat insulator is the equivalent of two electrodes butting together, the furnace being omitted. For such a state of affairs his conclusions may be correct, but it is not any commercial or practical state of affairs. For any given current passing through such a rod, or pair of contiguous electrodes, the temperature at the middle is nowhere near as high as for the same current passing through the same electrodes with a resistor or an arc between them.

If Mr. Hering had not omitted his furnace and had had a resistor between his electrodes, he would have approximated

* Printed and distributed in advance of the meeting.

commercial conditions and have had a higher temperature between the two electrodes than at their tips. Then the temperature gradients through the electrodes would have been very different from the ones he obtained. Mr. Hering says we must so proportion the electrode as to generate as much heat at the tip as in the furnace itself, or, in other words, that no properly constructed furnace should have a core of greater resistance than that of the electrode tip. This means that no commercial furnace approximately fulfils Mr. Hering's requirement for a properly built furnace—and conversely, that his formulæ do not apply to any existing commercial conditions. Commercial furnaces, arc, resistance with core like the carborundum furnace, resistance with charge as resistor, like the Readman-Parker phosphorus, or the

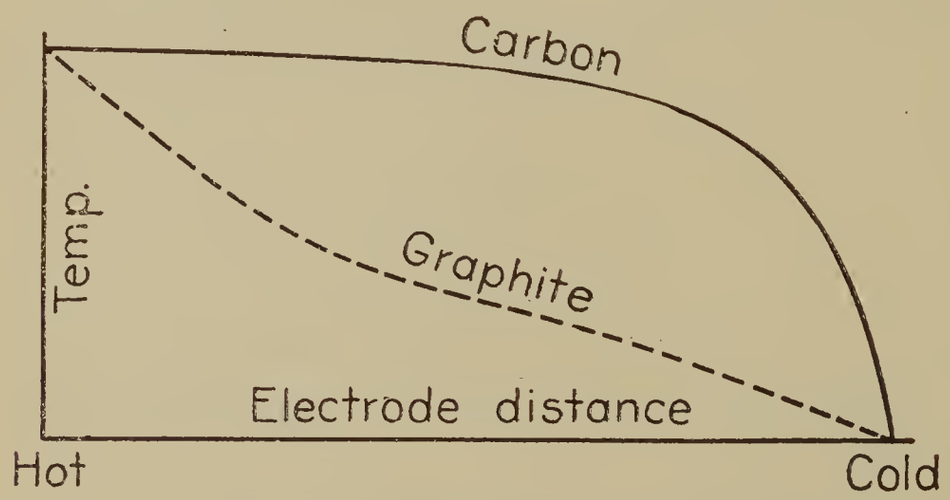


FIG. 1. Hering's Electrode Temperature Gradients.

Willson carbide or Héroult steel furnace; have a region between the electrodes where a higher heat is developed than in the electrode itself. Even if in some cases we could so design an electrode that its tip would be at the temperature of the furnace itself and prevent heat outflow through the electrode, we certainly cannot do so in an arc furnace. We must then consider the normal case, where we deal with electrodes with a hotter region between them. In such a case, we cannot accept the conclusions drawn by Mr. Hering, to the effect that "in carbon electrodes the high temperatures extend much nearer to the cold end than in graphite," the heat being "crowded toward the cold end." He also expresses this in a curve (Fig. 1).

Last year, in working out the problem of a fumeless tube for measurements with optical pyrometers in a carborundum furnace, we obtained these curves (Figs. 2, 3, 4). The furnace was 2′ long, 14″ wide and 12″ high, inside dimensions, packed with the normal charge for carborundum. The core was 10″ long and 2″ in diameter, of crushed carbon. The carbon or graphite electrodes were in each case new ones, 2′ long and 2″ in diameter. The parts projecting outside the furnace proper lay in troughs

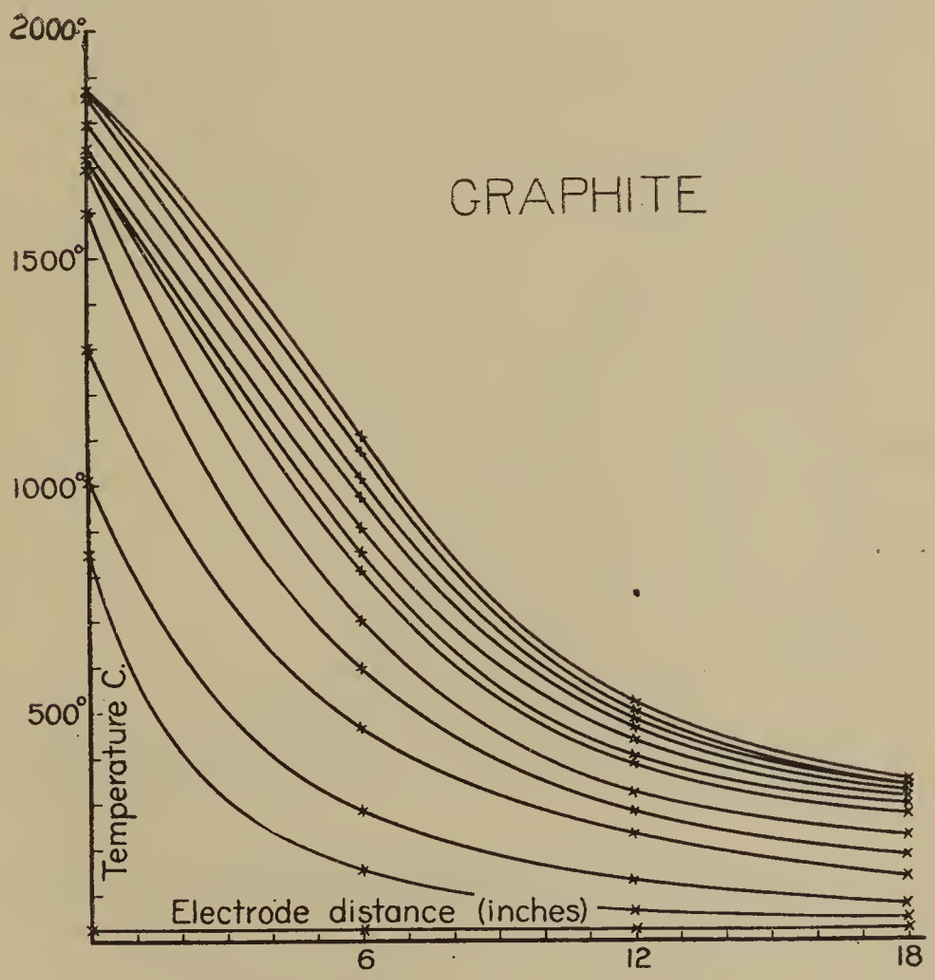


Fig. 2. Electrode Temperature Gradients—Run No. 59.

packed with siloxicon. Just at the juncture of core and electrode was inserted our fumeless form of temperature tube and readings of the temperature of the electrode tip made with a Wanner pyrometer. Six inches back from this tip was a hole bored for a thermocouple, and 12″ and 18″ back, other holes for nitrogen-filled thermometers. The runs each lasted 3 hours, the averages for current and power being 152 amps. and 10.3 kw. in Run 59 (Fig. 2) with graphite electrodes; 170 amps. and 10.6 kw. in

Run 60 (Fig. 3) with carbon electrodes; and 161 amps. and 9.4 kw. in Run 61 (Fig. 4) with carbon electrodes.

The curves show the temperature gradients at each 15 minutes of the run, starting at room temperature and ending at the final gradient reached. Neither final temperature nor rate of heating was exactly equal in the different runs, nor had the furnace reached an absolutely steady state at the end of the runs, as Mr. Hering insists upon, since these data were taken six months

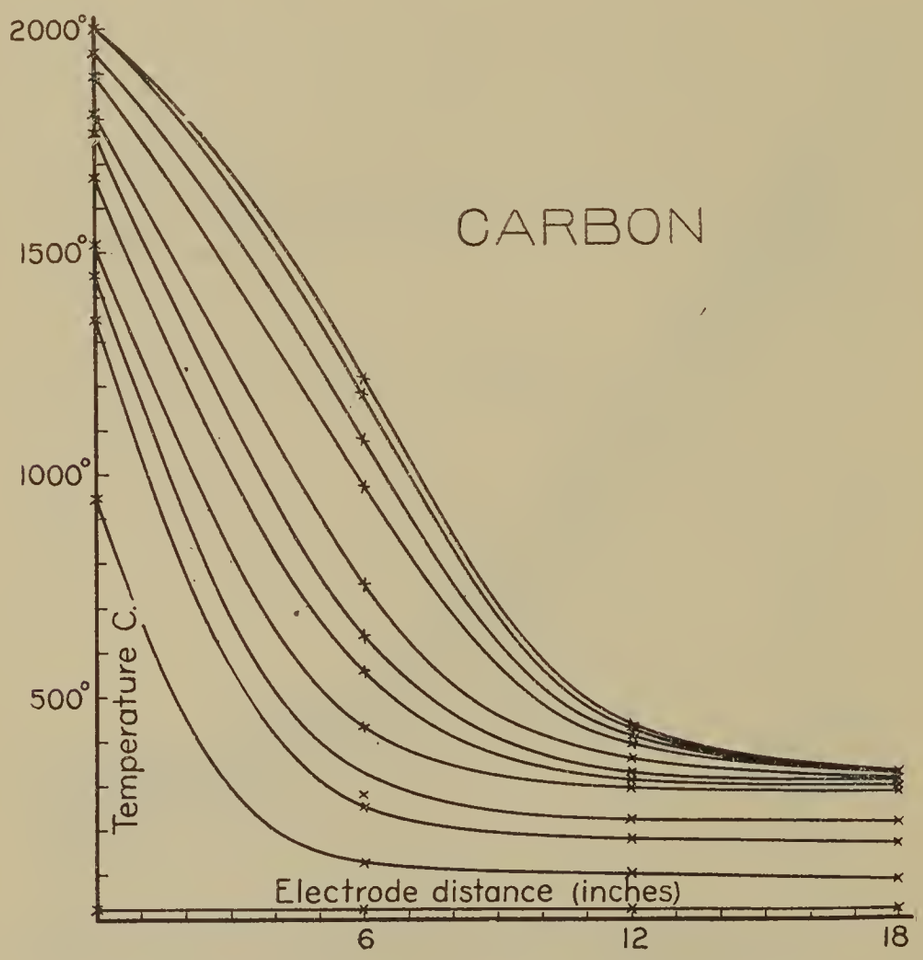


FIG. 3. Electrode Temperature Gradients—Run No. 60.

before his diagram appeared, and with no thought in mind of his formulæ or ideas. We have further work on this planned at Cornell, in which we will measure the gradients at a steady state.

Though we do not say that under some conditions his curves might perhaps not be approximated, under our conditions we did not, and under practical furnace conditions we think we would not reach gradients with anywhere near the difference between carbon and graphite electrodes that his diagram indicates. Hence

it seems to us that Mr. Hering takes too pessimistic a view of the carbon electrode in commercial furnaces.

The similarity of the curves for carbon and graphite is not due to graphitization of the tip. We have brought a piece of the tip of the carbon electrode used in Run 61, which will be seen on examination not to be graphitized to any appreciable extent.

Finally, since in the carborundum furnace at least it is not at

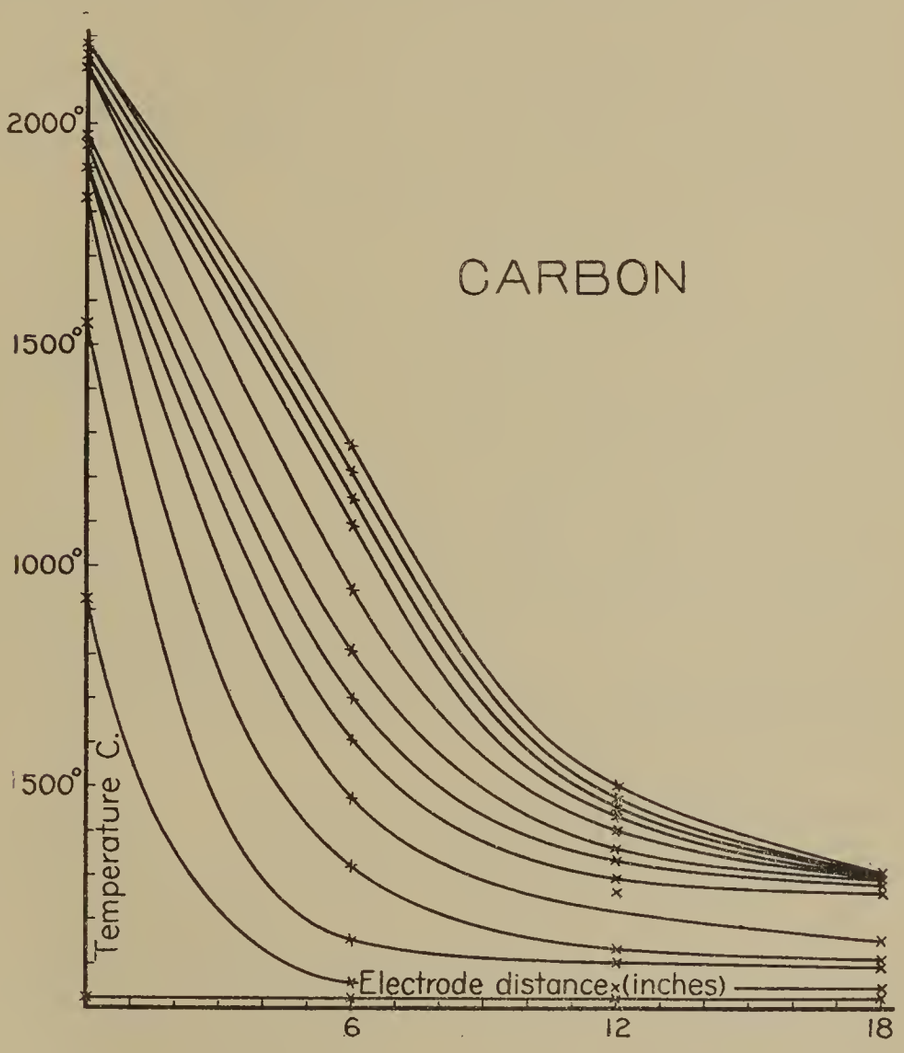


FIG. 4. Electrode Temperature Gradients—Run No. 60.

all difficult to measure temperatures between 1500° and 2500° C. to from 10° to 20°, not only concordantly, but accurately, and since this is the range in which most commercial furnaces operate, we feel that any electrode formulas should be really tested on carbon and graphite electrodes to temperatures beyond the 900° C. given as the highest point in Mr. Hering's table.

MR. GILLETT: Mr. President, I have here a piece of the electrode tip which I referred to, used in getting the carbon curves

which were obtained in Run 61. We obtained the temperature gradients not by electro-measurements, but by actual pyrometric measurements. I simply brought the tip to show that the remarkable similarity in the carbon and graphite curves is not due to graphitization. The difference between the curves for carbon and graphite is not necessarily in every case such as Mr. Hering gives. We were surprised to find that they were so nearly the same when we came to measure them actually. We simply found that the heat is not piled up at the cold end,—at least not in this one test,—and that has been borne out by experiments made on carborundum furnaces with a temperature from 1,800° to 2,500° C., and those curves show great similarity.

Mr. Hering: Mr. Gillett does not seem to have read the paper, or to have understood what he did read, because he says in the beginning in no uncertain terms, that "the temperature at the middle is nowhere near as high as for the same current passing through the same electrode with a resistor." I grant this may be as he says in average practice, but I do not grant him that it cannot be so, because all one has to do is to reduce the size of the electrode for a constant given current, and when the right size is thus obtained, the temperature will be that of the furnace. In his case it may not be so, but his furnace is not what I would call a properly designed one.

I have determined no temperature gradients. Nowhere in my paper is there given anything about temperature gradients, except in a short article which I published some months ago, in which some approximate gradients were shown merely to illustrate certain general relations. As I have determined no heat gradients, it is evidently not right for him to say that his results are not like mine. I have purposely avoided giving any heat gradients.

Moreover, his heat gradients are not comparable with mine at all, because he admits in his paper that he did not wait for the steady state to be reached. If he had waited for this steady state, his temperature gradients would have approached much more nearly to those I gave in that other article from which he has reproduced them.

Furthermore, he has reproduced them incorrectly, showing that he has not understood them, because he shows the graphite

curve making an acute angle with the vertical line in his Fig. 1. (The one I gave is on p. 129 of the March number of *Metallurgical and Chemical Engineering*.) Now, the very fundamental principle of the whole analysis is that at that point the temperature gradient *must* be horizontal. He has therefore misrepresented my curves.

He draws the conclusion that my results do not apply to commercial conditions. He is not justified in doing this. It may be that they do not apply to many of the present commercial furnaces, because we have not, as a rule, been running electrodes to such high end temperatures, and have not proportioned them correctly; but it does not follow that it cannot be done, because I have done it myself, and the results have been very satisfactory, and it would unquestionably improve existing furnaces greatly if these best conditions were approached as closely as possible.

I have made a number of calculations from his data, and will give them in writing in closing this discussion. I will then also answer some other points in his paper, and will show that his furnaces were very badly proportioned. It is no wonder, therefore, that he obtained such misleading results from which he draws such incorrect conclusions.

MR. GILLETT: I think Mr. Hering somewhat misunderstood my discussion, as I misunderstood his paper.

MR. LIDBURY: I notice that though the temperatures of the electrodes in this experimental measurement by Mr. Hering are carried out only in extreme cases to maxima slightly over 1,000°, yet the curves that Mr. Hering gives in this paper have certain values which go up as high as a temperature-drop of 2,500°. Is that by exterpolation from 900° C., or on what is that based?

MR. HERING: As the paper clearly states, those higher values are all exterpolated. But they are not mere continuations of the curves, because these exterpolated values must also have certain relations with each other, and must follow those empirical laws, if those laws are correct.

MR. LIDBURY: I take it that the values at 900° or 1,000° may represent no experimental results?

MR. HERING: Mr. Lidbury will find all these questions answered very fully in the paper.

MR. LIDBURY: And in view of Mr. Hering's explanation of the exterpolations, he would not want anyone to put very much confidence in them.

MR. HERING: I do not agree with Mr. Lidbury in that, at all. I myself unhesitatingly place considerable confidence in the exterpolated results, as I consider them to be very close approximations. They are certainly far closer than any other data we had, if, indeed, it can be said that we had any at all. But, as remarked in the paper, each person must be his own judge in that matter, and for that reason I have been careful to distinguish between the observed and the exterpolated results.

Moreover, Mr. Lidbury will see that as far as the proportions of the electrodes are concerned, the accuracy of the exterpolated values is of little importance, because the constants are very nearly the same for all the higher temperatures.

MR. JOS. W. RICHARDS: I take this opportunity of expressing my appreciation of the experimental data which Mr. Hering has published. So far as I know, it is the first experimental data published in this line. The tabulations of data on page 175, and the empirical laws deduced from these values, are an interesting and valuable scientific contribution.

The deductions obtained by Mr. Hering from the experimental data, concerning the values k and r, need to be carefully differentiated from the experimental data themselves. Mr. Hering has called the calculated values k and r the "Electrode Mean Values"; that is, the mean values of k and r for the actual electrode conditions with the temperature gradient in the electrodes which actually exists while in operation. This needs to be, especially by physicists, carefully distinguished from the *actual* values of k and r *at* any given temperature; they are intended only as the average values for a given range of temperature, and for the specific temperature gradient existing in the electrode. As such, and if reliable, they have valuable practical applications.

It seems to me that the value r obtained and given by Mr. Hering as a deduction from his experimental data is reliable, since its derivation involves nothing more than the use of Ohm's law and the experimental data. The value of k, as derived from the experimental data by Mr. Hering, involves, however, the

use of Mr. Hering's formula containing k and r, which formula as I understand it, is based upon the assumption of constant values of k and r throughout the length of the electrode. Therefore, the values of k obtained by the use of this formula involve that assumption also. Admitting that r is a correct value for the assumed conditions, k is uncertain because of the assumption of constant conductivities in the formula by which it is calculated. I am, therefore, not prepared to accept Mr. Hering's deduced values of k as really representing the "Electrode Mean Values" of the heat conductivity. They may be an approximation to the "Electrode Mean Values," but I should not wish to consider them as correct until they were derived from the experimental data by the use of a formula not open to the criticism of neglecting the variations of k with the temperature.

MR. HERING: Professor Richards is entirely wrong in his deductions, and he has either not read the paper or did not understand what he read, as it is stated clearly and repeatedly in this paper, and in others published elsewhere, that in the present method the temperature variations of the conductivities are absolutely and completely eliminated, and that the results are correct, whether there are or are not any such variations, and no matter how great or small they may be. Hence, Professor Richards is wrong in saying that the results are derived from a formula "open to the criticism of neglecting the variations of k with the temperature." The results are *not* derived from a formula open to such criticism, as the formula is entirely independent of what those variations may be. The results include these variations, whatever they may be, in these experimental constants, as perfectly as could possibly be desired, and far more perfectly than would be possible by any algebraic method. Professor Richards has not understood the formula, its derivation, or its application. He is also wrong in saying that the results only approximate the electrode mean; they are not approximations, but the absolutely correct electrode means, as far as those temperature variations are concerned, and they are approximate only in the sense that any experimentally determined quantities involve limits of accuracy in observation, and insofar as the heat insulation is not absolutely perfect.

He is wrong, too, in saying that there is "uncertainty" about the value of *k,* due, as he erroneously thinks, to an assumption of constant conductivities. There is no uncertainty whatsoever; on the contrary, *k* is very definitely and accurately the real and true electrode mean value. For perfect insulation the values of *k* are quite as positive, correct and reliable as those of *r,* which latter he admits are correct. He is mistaken in his assumption that the formulas used are correct only when *k* and *r* do not vary. He is, of course, correct in saying that the electrode mean values *for a range* of temperature are not the same as the values *at* a given temperature, as I have myself explained repeatedly.

Altho I have explained this repeatedly in recent papers, I will endeavor again to make it clear in my closing remarks.

Mr. A. L. Queneau *(Communicated):* I had occasion during last winter to make comparative tests of the heat conductivity of various refractories using clay-graphite bricks made by the Dixon Crucible Company as standard of comparison. I had previously determined the absolute heat conductivity of the clay-graphite brick by the Wologdine method, the value thus obtained being 0.025 calorie per sec. per sq. cm. per cm. for a difference of 1 degree Centigrade of temperature (0.105 watts per 1° C. cm. cube).

The method of Simonis was followed in the comparative tests. Two bricks of the material under test, cut to the standard dimensions of a brick "9-in. straight" 9 x 4½ x 2½ inches (22.5 x 10.2 x 0.63 cm.), were firmly clamped together along the 9 x 4½ (22.5 x 10.2 cm.) faces, and stood on end on one of the compound 5 x 4½ (12.5 x 10.2 cm.) faces, a machined plate of Acheson graphite, 5 x 4½ x ¾ (12.5 x 10.2 x 1.9 cm.), resting on the upper compound face. The bricks had been carefully finished, in order to secure close mechanical contact between themselves and the Acheson graphite plate.

The temperature determinations were automatically recorded at intervals of one minute by means of a Cambridge Thread Recorder, connected with four Le Chatelier thermo-couples through the intermediary of an automatic mercury switch. The thermo-couples were inserted in holes 1/16 in. (1.5 mm.) diameter, 2¼ in. (5.6 cm.) deep and 2 inches (5 cm.) apart,

the first couple being placed immediately below the graphite plate. The thermo-couple wires were insulated by means of asbestos thread, the small bar thus obtained was moistened with dilute water glass and sprinkled over with fine carborundum fire sand.

The flame of a carefully regulated blast lamp was directed and maintained on the central portion of the graphite plate; heating was continued until uniform temperatures were registered by the four couples, the four recorded lines becoming horizontal; it was possible to make use of a single recorder, owing to the different temperatures existing at the four points. Each test lasted about four hours.

Tests were made on the following materials: Fire-bricks of different brands, silica, magnesia, chrome, clay-graphite, carborundum, Acheson graphite and amorphous carbon. The results obtained at a maximum temperature of 600° C. confirmed, in general, those given by Wologdine.

Tests were also conducted on electrode materials, Acheson graphite and amorphous carbon; great difficulties were met with in the Acheson graphite bricks, owing to the high heat conductivity, and the figure given below is given only as an approximation.

	C. G. S. Units	Watts per 1° per Cm. Cube
Heat conductivity of Clay-Graphite Brick	0.025	0.105
Amorphous Carbon	0.10	0.43
Acheson Graphite	0.30	1.26

The following table may be taken as giving, under practical furnace conditions, the thermal conductivities of refractories, including electrode materials. It is understood that the figures do not apply beyond 1,000° C. for the refractories, and 600° C. for the carbon and Acheson graphite.

	Gram Calories Per Second per 1° C. Per Cm. Cube	Watts Per 1° C Per Cm. Cube
Acheson Graphite	0.30	1.26
Amorphous Carbon	0.10	0.42
Clay Graphite Brick	0.025	0.105
Carborundum "	0.023	0.10
Magnesia "	0.007	0.03
Chrome "	0.0057	0.024
Fire "	0.004	0.016
Silica "	0.002	0.008

Acheson graphite and amorphous carbon have, therefore, thermal conductivities of a different order from that of the refractories and like that of the metals, which are—

Aluminum	0.35	1.46
Steel	0.13	0.56
Copper	0.90	3.76
Brass	0.25	1.05

MR. CARL HERING *(Communicated)*: At the meeting Mr. Queneau called attention to the fact that his determinations of the heat conductivity of carbon agreed very well with mine. I regret to see that this remark has been omitted from the record, as have also the remarks of others referring to this agreement. The stenographer's report of my reply to Professor Richards' criticism of the correctness of the results also disappeared, and had to be rewritten from memory.

Dr. Kennelly's very interesting remarks are in my opinion of great value and importance, as he shows that certain results deduced from the empirical equations in my paper, correspond with results obtained in an entirely different way from a well-known physical law. When two entirely different, independent methods both lead to the same result, it is of course the best kind of an indication of the correctness of all the steps involved. Hence the remarkable and entirely unsuspected correspondence discovered by Dr. Kennelly, is not only of great interest from the standpoint of the physicist, but it also gives us a comfortable assurance that the empirical laws deduced in this paper are not likely to be far wrong. This is of considerable importance not only in pointing out to us new laws, but also because it gives us greater confidence in the exterpolated values for which we have as yet no reliable experimental data, and until they are determined we must rely on these exterpolations; these in turn show us that as far as the calculation of the cross-section is concerned, accuracy in these exterpolated values is not important, as they change very little.

Concerning Mr. Queneau's interesting communicated discussion, in which he has now added the actual figures, I notice that his figures for carbon and graphite agree surprisingly well with mine, considering the great difficulties in making accurate tests involving flows of heat. This is of considerable interest and value

for, if correct, it shows that the ordinary mean value and the electrode mean, are very nearly alike, thereby proving experimentally that what certain academicians tried to make us believe was a fatally large error in the earlier of my deductions (now superceded by others) is insignificant and is absolutely negligible in practice. I am therefore personally obliged to Mr. Queneau for giving this experimental proof of what has since been proved theoretically in a somewhat different form. These two proofs ought to put at rest all questions of the alleged lack of reliability of the methods and results of these investigations, and ought to satisfy even those academicians who "choke at swallowing a microbe."

Professor Richards again brought up that much discussed question of that academic correction factor supposed by him and others to be caused by the variation of the conductivities with temperature. Altho I have repeatedly shown in this and other papers, that by the use of these two new quantities, called E and S' in the paper (which are the only really rational and correct quantities in terms of which the essential properties of electrodes should be expressed and measured), these correction factors are entirely eliminated, as all such variations, however great or small, are embodied completely in these experimental constants—yet there still seem to be some who are not able to follow the deductions and to understand the final results. I may therefore be pardoned if I here make another attempt to make it clear by explaining more fully those features which do not seem to have been understood.

The general plan of this proof is to first assume certain new, definitely defined quantities, then to determine their values for any one particular electrode in accordance with those definitions, and then, finally, to show that these quantities are truly specific and therefore apply also to other electrodes of other dimensions. This may not be an orthodox method of proving something, but I believe its correctness cannot be questioned, and it is certainly far simpler than any algebraic proof would be.

In this explanation the two conductivities are dropped out of consideration entirely as factors in the calculation. Hence, neither their values nor the temperature variations of these values need

be known or considered; they may be great or small, and they may vary much or little, it does not matter; there are no conditions stipulated or involved. The only assumption is that these conductivities will always have the same fixed and definite values for the same material at the same temperatures; that is, that they are definite specific physical properties; no further assumption is necessary.

Instead of these conductivities, let us adopt two entirely new and different physical quantities, which we have selected and defined to be the watts per ampere, denoted by E, and the section per ampere and per inch length, denoted by S'; we, of course, have a right to make these new quantities anything we please. Their numerical values are then determined in any specific case in accordance with these adopted definitions, and must always agree with those definitions.

These two quantities really measure what we want to know about electrodes; unfortunately, they have as yet no names; it is as tho the ohm had not yet been named, and was therefore called the "volts per ampere"; but the lack of a name would not mean that it is not a true physical property, namely, resistance.

Let it be assumed now (to be proved later) that for each range of temperature these two quantities are true specific properties; that is, that like specific gravity, specific heat, specific resistance, etc., their values are independent of the dimensions of any particular piece. And just as the numerical values of these other specific quantities change somewhat for different conditions of temperature, pressure, etc., so the numerical values of these new quantities change somewhat for different temperature-drops in the electrode; hence, such values are given either in the form of tables, or (as in the present paper) in the form of equations.

Let it also be assumed that all electrodes are always operated so that there shall be no flow of heat thru the hot end, and that this, therefore, is the only condition of operation under consideration at any time; let this be referred to as operation "under normal conditions."

Being true specific quantities (so far, by assumption only), they may be determined experimentally once for all for any given material, with an electrode of any one selected size, and for each

of any desired number of temperature ranges, and then tabulated as constants; just as the specific resistance may be determined from a piece of a metal of any selected size under each of a number of conditions of temperature or pressure or tension, etc. This is what I did, as described in the paper preceding this one; the values of E and S' were therein calculated according to the above definitions.

Now, by definition E = watts $\div$ amperes, just as resistance might be defined as volts $\div$ amperes. Hence, as this is a definite specific quantity for each range of temperature, it follows, without any further proof or mathematical deductions, that the watts lost in any given electrode operating under normal conditions, are equal to the value of E (for that given temperature-drop) multiplied by the current. Hence, this method of calculating electrodes is proved as to E.

It will be seen that in this demonstration of the writer's method, the conductivities and their variations are completely eliminated from the calculation and from all consideration, altho they and their variations are really what determine the result; they may vary with temperature or not, and little or much; their values and variations are all taken care of very effectively in the tabulated values of E.

In precisely the same way, by definition, S' = section $\div$ (ampere $\times$ length). Hence, it follows (if this is a specific quantity) that the cross-section of any electrode operating under normal conditions, is equal to the value of S' (for that given temperature-drop) multiplied by the current and the length. All that was said above about determining the watts lost applies similarly to this section, and the result as to S' is therefore also free from any assumptions as to the values of or the constancy of the conductivities, altho they really determine that section.

I hope this is hereby made clear, and that the persistent claims of some academicians that my final method is based on constant conductivities, and that it is therefore unreliable, will hereby be completely set at rest.

It remains to be demonstrated that these new quantities are true specific quantities under the normal electrode conditions. Altho this will appear self-evident to anyone giving it due

thought, the following proof, based on the simple, neat and ingenious one devised by Dr. E. F. Northrup, and referred to in my papers, ought to satisfy even the most skeptical academicians who have persistently doubted its correctness. It might be added here, for their benefit, that we are here concerned only with electrodes of uniform cross-section from end to end, and that the Thomson effect, heterogeneity of material, lateral leakage, chemical changes in the material, and all other like minor matters which so greatly complicate the complete mathematician's equations, are here considered to be non-existent.

If it can be shown that the values of E and S', for any one particular range of temperature, are the same for any cross-section and for any length, then they are true specific quantities.

Imagine an electrode, while operating under normal conditions, to be cut in two, lengthwise. It is evident that this will change nothing in its operation, as neither heat nor current was traversing across that plane. Hence, one of these halves may be removed without causing any change in the other, in which the current and the cross-section will then be just half of the original; the heat gradient of the remaining half will, of course, remain the same. The watts lost in the remaining half will therefore now be half of what they were, and will therefore still be equal to *the same* E multiplied by the current thru that half, namely, by half the original current. The same will evidently be true for any other fractional part of the original cross-section; hence, for all sections. That is, *E is the same for all sections*, and is therefore a true specific quantity in so far as the cross-section is concerned. No questions concerning the conductivities or their variations are here involved; they may have any values, great or small.

Now, imagine this original electrode to be cut transversely into a very large number of thin laminæ, like the leaves of a long row of books. Suppose, now, every alternate leaf was removed, and the rest brought together, making a new electrode just half as long. It is supposed, of course, that the contact resistance between the leaves is neglected, or is always the same per leaf. Now, to produce the same amount of heat and the same temperature conditions in each one of the remaining

laminæ, as were before produced in two neighboring ones, will evidently require twice the current that passed thru it before; hence, the current must be doubled.

Nothing will hereby be changed in the heat gradient, except that it will be condensed or shortened to half its length; the total drop from end to end is the same by definition; the value at the middle, or at 1/10 or 1/100 of its length from either end, will be the same in one as it is in the other, because the total drop is the same. In other words, the heat gradient will be twice as steep at every point; the drop in each leaf will be the same as it was in two leaves before. The new heat gradient will be like the old one seen thru a cylindrical lens, or drawn to a shorter horizontal scale. This is true, no matter how irregular the shape of the curve of this heat gradient was, provided, only, that the laminæ were thin enough and numerous enough.

Now the resistance of this new electrode will be just half as great, as one of each pair of minute laminæ has been removed. The current being doubled, and the resistance halved, the watts will be doubled; hence, they will be again equal to *the same E* multiplied by the new current. The same argument applies equally well to any other length; hence, to all lengths. Therefore *E is the same for all lengths*, and is therefore a true specific quantity in so far as the length is concerned.

Having proved the same for the section, it follows that *this quantity E is independent of both section and length and is therefore a true specific quantity.*

By the same method is can be shown that the other quantity, S', is also a true specific quantity. If, for instance, the original electrode is cut in two, lengthwise, the value of S' is the same for each half because the current is half as great in each; hence, S' is the same for all sections. In the second case, if half the transverse laminæ are removed as before, we have found that the current will be twice as great, and therefore the value of S' will again be the same, because the length has been halved, the value of S' by definition being $S' =$ section $\div$ (amperes $\times$ length). Hence, it will be the same for all lengths. *Being the same for any cross-section and any length, this quantity, S', is a true specific quantity.* Here, again, we are not in any way con-

cerned with the values or the variations of the conductivities, they being taken care of completely in the experimentally determined values of S'.

In introducing the quantities k and r in the present paper, the writer did so merely to show how their electrode mean values could be determined from these new quantities, if it is desired to know them; but it was clearly stated that k and r were no longer involved as factors in the present simplified method in which they need not be known or considered at all.

In view of the criticisms made by some academicians of the writer's original paper in the preceding volume of these Transactions, it may be of interest to add that the present simplified treatment of this subject, the correctness of which, it is believed, will no longer be questioned, gives exactly the same results as the original and more complicated method described in that former paper, when the complete method described therein is used; that is, when the constants are determined as therein described. Hence, if the present treatment is correct, the complete method described in that former paper is correct, and does not involve the supposed errors on which so much stress had been laid by some of the critics, none of whom could, however, show that there were any real errors, but simply assumed them to exist because their mathematical treatment became too complicated to give a solution. The case is of interest as showing how an approximate mathematical treatment (and the unfinished highly mathematical solution offered by one of the critics in the last volume of the Transactions is at best only approximate) can be extremely complicated, when the mathematically exact one (as I believe the present one to be) is ridiculously simple.

Those interested only in the final results of these investigations, as far as they pertain to the calculation of electrodes, will find this portion summarized in a short article in the *Electrical World,* June 16, 1910, page 1598, in which the necessary constants have been reproduced and the rules given in simple terms.

The same issue contains, on page 1571, an editorial reference to this article, from which the writer desires to include the following in the present discussion:

"Hering's law of minimum power waste and zero heat escape from the furnace is, therefore, practically sound, and is likely to be classical. It is not merely an intellectual truism, it is also a highly practical rule. If the rule is neglected, there will probably be either a chilling of the furnace by thermal cooling near the entrance of the electrodes, or a superheating of the electrodes in the walls, with a tendency to more rapid disintegration; or an unnecessary waste of power. The question is quite important. * * * The data are now so simple in form that no electric furnace designer can have any difficulty in understanding them."

Replying, now, more fully to Mr. Gillett's discussion, the following approximate deductions may be of interest to show how badly designed his furnace was, and it is therefore no wonder that his results misled him into wrong conclusions.

Taking the case of his graphite electrodes, Fig. 2, 24 in. long and 2 in. in diameter, and assuming that his graphite was about the same as that for which I obtained the electrode constants, he would have obtained much better results if he had made them only about 1 in. in diameter, hence, about ¼ the section. His total loss would then have been only about 225 watts, when at present it must have been nearly 500 watts, including, of course, the large amount of furnace heat which his extremely large electrode was carrying off. Hence, his loss was more than double what it could probably have been reduced to by correct design. It is no wonder, therefore, that he obtained the very bad heat gradients that he did, and they are, of course, not properly to be compared with mine, in all of which the heat gradient must be horizontal at the hot end by premise.

Moreover, he indirectly admits that his furnace product was chilled around the end of the electrodes, which is quite in accordance with the above. If he had proportioned the electrodes correctly (provided his electrodes would stand that temperature) the whole interior of his furnace would have become active and available, instead of only a small part of it.

Or if, with his present outfit and proportions, he had increased the current to about 600 amperes instead of 152, he would not only have obtained an output which is much greater than in that

proportion, but the furnace would also have been more efficient, assuming, of course, that the electrodes and the linings would stand that temperature. These results are, of course, only rough approximations.

Mr. Gillett shows in his paper that he either has not read or has not understood my papers. The temperature in the middle of the electrode in my test is always *made* to be that of the furnace; hence, the conclusion in his first paragraph is, of course, unwarranted and incorrect. He is also wrong when he quotes me as saying that there should be "generated as much heat at the tip as in the furnace itself"; that would be absurd. I deny ever having made such a statement, and hope I was never guilty of such a loose and improper use of terms. I hope, for the sake of his students, that he meant to say "temperature," instead of "heat," which, of course, is quite a different matter. He should be more careful in quoting others in print.

It unfortunately may be true that "no commercial furnace approximately fulfils Mr. Hering's requirements for a properly built furnace," because I think it is true that most furnaces are so poorly designed that there is a loss of heat, and sometimes a very large one, thru the electrodes, which could be saved by properly proportioning the electrodes. His conclusion therefrom, namely, "and conversely, that his formulæ do not apply to any commercial conditions," is not only logically incorrect, but entirely incorrect in fact. My conclusions apply to any commercial furnace in which the electrode and walls can withstand the furnace temperature. And under these conditions, if, as he says, there is a higher temperature in any resistance furnace than at the ends of the electrode, it is the best possible proof to me that the design is faulty and that both the efficiency and the output could be increased, perhaps very greatly, as in his own case.

I do not agree that the cases he cites are "normal"; the word "usual" would be better; they would be normal after the change. Nor is his term "pessimistic" logical, as I was stating facts and not opinions.

He says he "cannot accept the conclusions drawn" by me, as to the different heat gradients in a carbon as compared with a graphite electrode. His reasons, being based on an entirely incor-

rect interpretation and understanding of what I said, do not apply to what I did say; hence, I cannot agree with his conclusions. He would, of course, naturally obtain similar heat gradients for carbon and for graphite when there is such an extremely large outflow of furnace heat thru his electrodes, as there was in his case. It was entirely unnecessary to make those tedious experiments in order to show this; it is almost self-evident. He shows that he did not understand the very first principle of my treatment of the subject, which is that the heat gradient at the hot end must always be horizontal; it is forced to be so by premise; hence, if it is not so in his case, that itself is evidence that my results could not be judged by his experimental evidence, as the prime conditions are different. Mr. Gillett would have done well to have studied my papers more carefully before going into print with such an attack on the results; such attacks can do no good, and may do much harm.

Mr. Gillett endeavors to give the impression that the reason why I did not go to still higher temperatures was that I could not measure them. This again shows that he either did not read my paper or is misrepresenting me again, as the reasons are clearly stated and were not that I could not measure them. The facts are that I did make numerous measurements at higher temperatures, but threw out the results for reasons given. Mr. Gillett should read a paper before he criticises it in print.

His Fig. 1 is alleged by him to be a reproduction of mine. This is not true, as anyone can see by comparing it with the original, which was published on p. 129 of the March, 1910, issue of *Metallurgical and Chemical Engineering*. Mr. Gillett has very materially altered the important and typical part of the graphite curve, namely the horizontal part at the hot end; he shows it decidedly inclined. If this were not the very basis of his criticism, it would not be of so much importance. As he represents my curve, the comparison between the two is, of course, absurd and irrational, while, as I showed them, the comparison is a rational one, because both were operated under the same conditions. If Mr. Gillett did not notice this change in the typical part of the curve, he shows that he did not understand the very first principle of the paper he was criticising. He should be more

careful before going into print with alleged reproductions of the work of others. To attempt to make an author's work ridiculous by misrepresenting him, is entirely improper and cannot fail to reflect more on the critic than on the author.

A paper read at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 5, 1910, Dr. J. W. Richards in the Chair.

A NEW RADIATION PYROMETER

By C. E. Foster.

The manufacture of iron and steel, and their subsequent heat treatment, provide a very wide and interesting field for pyrometry. In the case of the melting operations the conditions practically prevent the successful use of any type of pyrometer in which some part has to be raised to the actual temperature to be measured, for the following reasons:

1. The temperatures met with run very near to the safe limit for the sensitive part of the pyrometer, even if it can be adequately protected.

2. The chemical activity of the metal, slag and furnace gases make it difficult to properly protect the pyrometer, without making it very slow in action.

3. The molten metal itself is often very difficult of access.

For these reasons the radiation pyrometer is practically the only type that can give hope of successful use on such work.

Radiation pyrometers are of two broad classes—"Optical" and "Total Radiation." In the optical instrument the measurement depends upon matching the color or intensity of the luminous radiation against a standard carried by the pyrometer itself. The reading is not direct in temperature, but requires reference to a table or curve of calibration. Consequently, the optical pyrometer is more suitable for the laboratory than for general works' practice.

The "Total Radiation" pyrometer is simpler and has less of the personal element in it. It works with the whole range of heat radiations, both visible and invisible, and consequently has available much more energy than the optical instrument. The total radiation instrument can be made direct reading and practically automatic in action.

The instrument to be described I have designed with a view to making its operation quick and very simple; at the same time the construction of the instrument is very robust and not liable to derangement. Fig. 1 illustrates the arrangement of the receiving

tube diagrammatically. At the front end is a diaphragm EF, while at the opposite end is a concave mirror C. The radiant heat from any hot body, such as AB, enters the opening in the diaphragm EF, and a fixed proportion of it strikes the mirror C. It is then focused at D, so that at D will be a focused image of the aperture EF. Now, if a single simple rule is followed, the action of the instrument will be just as if the hot body were actually at the aperture EF; consequently, the focusing is done once for all in manufacture and need never be considered in use. This fact supplies the reason for the name, Fixed Focus Pyrometer. It will be seen that in order that the aperture EF, as seen from all parts of the mirror C, may be filled with radiation from the hot body, the hot body must fill or overlap a section of the cone GAB, or any extension thereof. If the hot body is

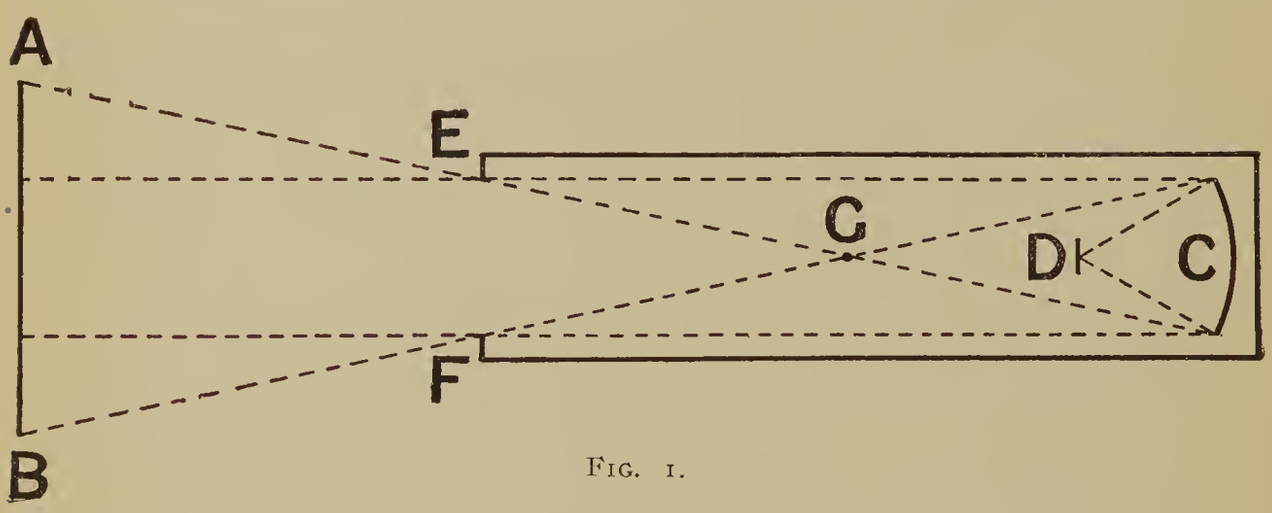


FIG. 1.

larger or nearer than is required by this condition, it will simply result that the outer edges are out of the measurement, since they can only radiate heat on the walls of the tube, and these are made non-reflecting. If we can readily find the apex G, of the limiting cone, then we can say that the maximum working distance must be a fixed multiple of the diameter or smallest dimension of the hot body surface.

In the instrument on the table the position of the apex G, is marked by the center ring, carrying the clamping nut; and the fixed multiple is 10. An example will illustrate the rule for maximum working distance. If the hot body is a steel billet whose smallest dimension is 6 inches (15 cm.), the working distance from the surface of the billet to the center ring on the receiving tube must not exceed 60 inches (1.5 meters), and, of course, the axis of the tube must be in line with the center of the

billet. Similarly, if the hot body be a peep hole in a furnace door, and the peep hole has a diameter of 3 inches (7.5 cm.), the maximum working distance from the inner edge of the peep hole must not exceed 30 inches (0.75 m). In practice the user does not trouble to accurately measure the distance, but holds the tube well within the maximum distance thus avoiding the necessity for measurement or for very accurate pointing. In studying the very simple theory of this design, the essential point to bear in mind is that the mirror is always delivering at D a focused image of the aperture EF.

The temperature indication is secured as follows: At D is the "hot junction" of a very small but efficient thermo-couple. This is connected through a flexible cable to an indicating milliammeter. The scale of the milliammeter does not show current, but is made direct reading in temperature of the hot body. The "cold junction" of the thermo-couple, where its elements join the rest of the circuit, is about 4 millimeters (3-16 inch) from the hot junction, consequently any rise or fall in the temperature of the receiving tube will affect both junctions alike. The reading on the indicator depends upon the *difference* in temperature between the hot and cold junctions, and is consequently independent of the actual tube temperature. The deflections of the indicator itself are also practically the same for all instrument temperatures.

The calibration of the indicator is based upon the well-known Stefan-Boltzmann law of radiation, which law the instrument is found to follow very closely. The actual adjustment is, however, always checked upon a high temperature furnace against a set of standards, so that should there be any departure from the Stefan-Boltzmann law it will be taken into account in calibration, and does not appear as an error.

The increasing study of high-temperature processes, particularly those connected with the open-hearth and electric furnaces, indicates a field that will be usefully covered by this pyrometer. Its accuracy is good and permanent, while it is easily portable, and may, with safety, be placed in the hands of unskilled users.

The normal calibration of the instrument is made to apply to "black body" radiation. Such radiation is given out from the

and therefore this calibration applies to a large number of cases met with in practice. Where the "black body" condition does not obtain, as, for instance, on a stream of molten metal, out in the open, the indicator is specially calibrated for this work, so that it reads true temperatures. In measuring the pouring temperature of a stream of molten steel, the best way to proceed is as follows: Before tapping, fix the receiving tube, by means of the center ring and nut, so that it will point at the *side* of the stream of metal, close to the spout. Place the tube near enough inside of a uniformly heated furnace through a small opening,

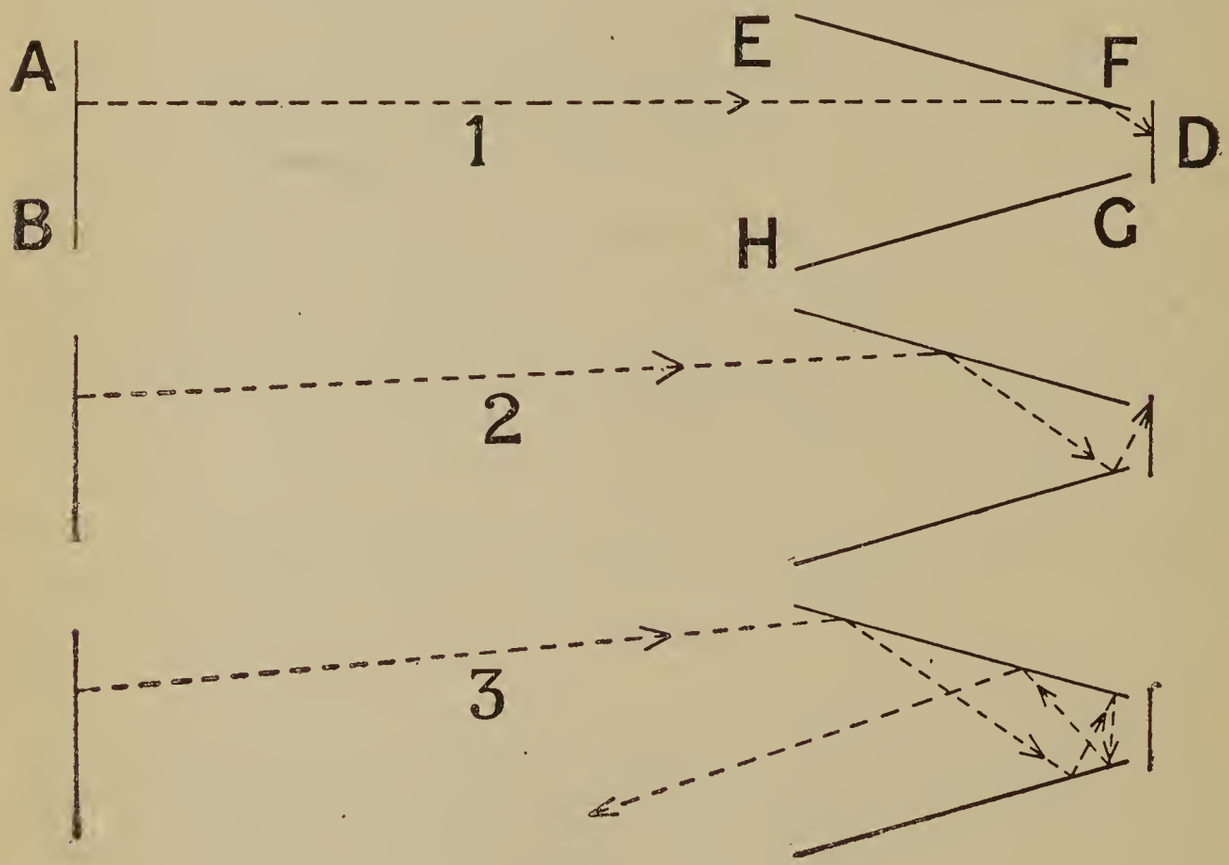


FIG. 2.

so that the working distance rule will be followed, even when the stream fluctuates in size and position, as it usually does. The side of the stream, close to the spout, will be free from slag or oxide, and will present a surface whose radiation factor is constant; hence, the ability to scale the indicator to meet the case, notwithstanding the fact that "black body" conditions do not apply.

The instrument is useful also for measuring the temperatures of billets and bars before and during the rolling processes, and an approximately steady reading, within 1 percent of the final, will be reached in from 10 to 15 seconds. The sensitive parts of

the instrument being at the bottom of a long closed tube, there is little chance of their getting damaged. The high efficiency of the heat concentration gives a comparatively large current available for deflecting the indicator. The indicator is, therefore, a robust instrument that does not require accurate levelling in use, nor clamping or other manipulation for carrying.

The question will probably arise as to the reason for using the concave mirror as a heat concentrator. The answer is that it is the most efficient means available. If it is contrasted with a conical reflector, such as was used by Melloni in his physical experiment on radiant heat, it will be seen how far superior is the concave mirror. Fig. 2 shows the action of Melloni's cone.

AB represents a hot body, and EFGH the cone. D is the sensitive surface. It will be seen that a ray, such as 1, reaches D after a single reflection, while one such as 2 suffers double reflection; 3 never reaches the sensitive surface at all, because of the geometric result of multiple reflection. There is a further trouble with a cone that renders it more difficult to use with accuracy. At each reflection the heat ray loses some of its energy by absorption. This absorbed heat is conducted towards the apex of the cone, and is there radiated, after a considerable interval of time, on to the sensitive surface. This effect tends to make the apparatus slow in coming to a steady deflection; there is a long continued creep after the first deflection. It will illustrate the high efficiency of the newer arrangement to state that the E. M. F. developed when the tube is pointed at a furnace at 1,300° C. is greater than would be given by a Le Chatelier thermo-couple actually inserted in the furnace.

DISCUSSION.

Dr. J. W. Brown: I would like to ask Mr. Foster if this instrument is more or less sensitive than the one he described last year?

Mr. C. E. Foster: The instrument that was the subject of my paper last year was the Fery Spiral Pyrometer, which does not have a millivoltmeter. I remember, however, that in the discussion of that paper, reference was made to the indicating instrument supplied with some of the earlier Fery instruments, and that it

was stated that trouble had been experienced with the delicacy of these. They were suspended coil instruments. Undoubtedly the indicator on the table is far more robust than the old Fery indicator. It is only fair, however, to state that we have for a long time very much improved the Fery instrument, and the indicator now supplied with it would be very nearly as strong as that of the fixed-focus instrument.

THE CHAIRMAN: I believe I understood you once to say that you had perfected this instrument to the extent that it could be dropped three feet to the floor without disastrous results?

MR. FOSTER: Three feet was the limit of fall that put the instrument out of commission, in a series of progressive trials.

DR. BROWN: What accuracy do you claim?

MR. FOSTER: At any point above the middle of the scale, better than 2 percent; it is difficult to read to such a small percentage on the lower part of the scale, as that is more contracted. The calibration accuracy is always within 1 percent.

MR. X.: I would like to ask Mr. Foster what standards he has been using?

MR. FOSTER: We have shouldered that whole trouble on the Bureau of Standards, and rely upon them. We have a set of standards that have been checked at Washington, and our calibration is made against these.

THE CHAIRMAN: What is the higher limit that you have found it to give indications, or have used it for? Have you used it on electric furnaces, for instance?

MR. FOSTER: I have never actually used it on an electric smelting or melting furnace, but I do not see why there should be any practical upper limit. The scaling above actual test points would be according to the Stefan-Boltzmann law, and the assumption that this law holds by exterpolation is, I believe, thoroughly justified by practical results.

THE CHAIRMAN: Would it injure the instrument if it were pointed towards the sun, in an effort to estimate the sun's temperature?

MR. FOSTER: The sun covers such a small angle that it would not damage the instrument, since it does not fill the necessary limiting cone. Its temperature is so high that, if it covered a large enough angle, it would destroy the thermo-couple in the receiving tube.

A paper read at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 5, 1910, President L. H. Baekeland in the Chair.

DUCTILE TUNGSTEN AND MOLYBDENUM.

By Colin G. Fink.

Tungsten has heretofore been known chiefly as a steel-hardening metal. In recent years, however, tungsten has become an important material for filaments of incandescent lamps, and is today the most efficient metal for this purpose, owing to its high melting point (3,000° C.; that is, higher than that of any other metal) and its low vapor tension.

It is well known that tungsten is described in all of the text-books as a brittle gray metal, and that numerous attempts have been made to reduce it to ductile form, as is evidenced by publications emanating from various research laboratories. Roscoe and Schorlemmer, in the latest edition of their "Treatise on chemistry," state that "The purest forms of tungsten at present obtainable are hard and brittle, and are not ductile either at ordinary temperatures or when heated."

The metal has ordinarily been obtainable in commerce in the form of a dark gray powder, usually made by the reduction of the yellow oxide by hydrogen or by carbon. This powder, when bought on the open market, is generally impure, and is purified by various well known methods, particularly if the metal is to be used for filaments of incandescent lamps. These filaments have been made on a large scale, and are in common use in this country and abroad. Even in ordinary commercial lamps, the filaments are of a degree of purity so high that no impurities can be discovered by the most searching known methods of chemical analysis. Not only is this true, but these filaments, during the course of commercial production, are exposed to temperatures

high enough to drive out by mere vaporization almost any impurity.

Nevertheless, these filaments show no traces whatever of ductility or even pliability, but, on the contrary, though they are strong enough for mounting in commercial lamps, they are exceedingly brittle and incapable of taking a permanent set. Attempts have hitherto been made to produce ductile tungsten by various purification processes, and all without success. Such have been by varying the ore from which the tungsten is obtained, by trying first wolframite, an iron-manganese tungstate, and then scheelite, the calcium tungstate. Whichever ore is used, it is customary to produce from it the yellow oxide, and a high degree of purity has been sought by repeated precipitations. Various methods of reduction have been tried; among other reducing agents used have been hydrogen, carbon, aluminium, zinc and magnesium. Reduction has also been effected by electrolytic methods. Since tungsten metal produced in this way has been so pure that no impurities could be detected by ordinary chemical or physical means, and yet has retained its characteristic hardness and brittleness, it has generally been concluded that the metal is entirely lacking in that physical property which is ordinarily termed ductility.

Announcement has, however, recently been made of the production of tungsten in a form in which it is ductile. This ductile tungsten would seem to be a new substance, from the point of view of the physical chemist, and it has seemed to me that this Society would be interested in learning something of the properties of this product, since only those of us who have been connected with the Research Laboratory of the General Electric Company have as yet had an opportunity to study it.

Ductile tungsten is a bright, tough, steel-colored metal, which can be drawn into the finest wire, much below one-thousandth of an inch. The tensile strength of the wire increases as the drawing proceeds; or in other words, the more the metal is mechanically worked, the tougher and stronger it gets. In the following table a few figures on the strength of tungsten wires

are given. They are the average obtained from a large number of measurements.

TABLE I.

Tensile Strength.

TUNGSTEN WIRE

Diam. in Thousandths of an Inch Diam. in Millimeters	5.0 0.125	2.8 0 .070	1.5 0.038	1.2 0.030
Lbs. per square inch . . .	460,000 to 490,000	480,000 to 530,000	550,000 to 600,000	580,000 to 610,000
Kg. per square mm. . . .	322 to 343	336 to 371	385 to 420	406 to 427

MOLYBDENUM WIRE

Lbs. per square inch . . .	200,000 to 260,000	230,000 to 270,000	270,000 to 310,000	. . . . . .
Kg. per square mm. . . .	140 to 182	161 to 189	189 to 217	. . . . . .

A piece of hard-drawn piano wire, tested with the same apparatus, registered, on the average, 507,000 pounds (356 kg. per sq. mm.), the diameter of the wire being three-thousandths of an inch (0.075 mm.). According to Schnabel, aluminium shows a similar behavior as regards the effect of drawing: Cast aluminium gives but 17,000 pounds per square inch (11.9 kg. per sq. mm.), whereas the drawn metal has a tensile strength of 36,000 to 39,000 pounds (25.2 to 27.3 kg. per sq. mm.).

The density or specific gravity values of ductile tungsten likewise increase with the amount of working. The values for ductile molybdenum were also determined at our laboratory.

Table II.

Specific Gravity.

Diameter		TUNGSTEN	MOLYBDENUM
		Before Drawing	
		18.81	10.02
nches	Mm.	After Drawing	
0.150	3.75	19.30—19.30	10.04
0.010	0.25	19.58—19.64	10.29
0.0015	0.038	19.86—20.19	10.32

Martin (1907) found the density of melted tungsten, analyzing 98.96 percent pure, to be 16.28; Moissan (1896) and Weiss (1910) give the values 18.70 and 18.72 for the brittle metal. As is seen from the table, the density increases very appreciably with the amount of mechanical working applied. This same phenomenon is well known in the case of copper, zinc and other metals. The density of cast copper, according to Marchand and Scheerer, is 8.92, and that of rolled and hammered copper 9.95. Distilled zinc gives 6.92, and wrought zinc, 7.25.

The electrical resistance and the temperature coefficient of each of the two metals are given in Table III. We used the Wheatstone bridge method. The resistance was measured at room temperature and at 170°, employing two oil thermostats.

Table III.

Resistivity (25°) in microhms per cu. cm.			Temp. Coeff. per degree between 0° and 170° C.
Tungsten	*d.*	6.2	0.0051
	a.	5.0	
Molybdenum	*d.*	5.6	0.0050
	a.	4.8	

The values marked *d* are for hard-drawn wire, those marked *a* were obtained after annealing. The resistivity value for tungsten is a good deal lower than that given by Gin. (Trans. Am. Electrochem. Soc., XIII, 483.) The coefficient for copper (0° to 160°) is 0.00445(Reichardt), and the resistivity values: (d), 1.62 and (a), 1.58.

The hardness of both tungsten and molybdenum depend very much upon the amount of mechanical working the metals have

been subjected to and upon the presence of impurities. Whereas the hard varieties scratch glass, the soft varieties are easily cut with a file. The thermal coefficients of the two metals were determined on wire five-thousandths of an inch in diameter. A reading of 1° on the scale was equivalent to an elongation of the wire equal to 0.000545 inches. The values obtained are 336×10^{-8} for tungsten and 360×10^{-8} for molybdenum, the temperature range being 20°-100°. The platinum value is 884×10^{-8}. (Dulong and Petit).

Chemically, the two ductile metals behave similarly in many respects. The drawn wire retains its lustre almost indefinitely. Both metals are readily attacked by fused oxidizing salts, such as $NaNO_3$, $KHSO_4$ and Na_2O_2. Acids (HCl, HNO_3, H_2SO_4) attack tungsten very slowly, but molybdenum rather readily. I have heated fine-drawn tungsten wire in a mixture of chromic and sulphuric acids for sixteen hours and could detect only a very small loss in weight.

Original weight: 16.7330 grams; after 16 hrs.: 16.7329 grams.

Original weight: 1.3638 grams; after 14 hrs.: 1.3635 grams.

Apparently the metal becomes passive, just like iron.

This work was carried out at the Research Laboratory of the General Electric Company, at Schenectady, N. Y. Naturally, a number of my colleagues, chemists and research men, have also been active in it, foremost among whom is Dr. Coolidge.

Schenectady, April 30, 1910.

DISCUSSION.

MR. KING: I would like to ask as to the behavior of the metals on long continued heating to high temperatures; that is, as to whether they crystallize or not.

DR. C. G. FINK: That depends very much upon the purity of the metals.

THE SECRETARY: In justice to Dr. Fink I would say that the patent situation in regard to many of the problems which have

been raised will not admit of free discussion of the points involved, so that answers to many of the questions are not permissible at this time, as I understand it, and many questions which might be asked cannot be answered.

MR. L. A. PARSONS: Mr. Chairman, what we are mostly interested in is how they get it ductile.

MR. FINK: That will be described in another paper, which is going to be published a little later.

A paper presented at the Seventeenth General Meeting of the American Electrochemical Society, at Pittsburgh, Pa., May 7, 1910, President L. H. Baekeland in the Chair.

A NEW METHOD FOR THE ELECTROLYTIC WINNING AND REFINING OF METALS

By Edwin M. Chance.

It has always seemed to me that the methods now in vogue, of electrolytically winning metals from mattes or speisses, were open to serious criticism, and hence great improvement. Of course these methods are well understood, and their defects clearly seen.

A few, however, of the difficulties encountered in the operation of the usual electrolytic refining plant, wherein matte anodes are employed, may be touched upon. Firstly, the heterogeneous character of these anodes causes them to pit and honeycomb to a serious extent under the attack of the current, necessitating frequent and costly re-casting. Then, too, impurities contained in these anodes, being oxidized, enter the bath and foul it to such an extent that it must eventually be run to waste. The difficulty in obtaining a pure and adherent cathode deposit is also characteristic of these wet processes.

Might not the most desirable method of treating mattes or speisses be an electrolytic one, wherein the different substances to be handled, are treated in a fused state?

Robert H. Aiken has patented such a process (U. S. Letters Patent No. 873,648, under date of December 10, 1907). Mr. Aiken's method consists in fusing a sulphide ore containing nickel, copper, and iron, such as pyrrhotite, or the matte from such an ore, and directly electrolyzing the same. He claims that the copper and nickel may be readily separated as metal, from the fused sulphide while the iron sulphide will remain undecomposed if the difference in potential between the poles be properly controlled. If, after the removal of copper and nickel, the voltage be increased, the iron will be deposited. In both cases sulphur is liberated at the anode.

It would seem that insuperable obstacles would lie in the way of

the commercial application of such a process. First of all I believe that there would be considerable loss of electrical energy, as I understand that such a bath would conduct current directly, without the current doing electrolytic work. The separation of the metals would not be sharp. Mr. Aiken himself acknowledges that the copper-nickel deposit is largely contaminated with iron, which he suggests may be removed by subsequent refining. It seems reasonable, also, that metals so deposited would retain considerable sulphur.

In view of the above facts I set about to determine if it were not possible to apply the many excellent features of the wet electrolytic refining of mattes to their treatment in a fused state.

The thought suggested itself, that if the matte were fused, a fused electrolyte superimposed upon it, and electrolysis started, many advantages might accrue. The deterioration of the anode and occlusion of metals which it was desirable to attack, would be obviated, the molten anode automatically maintaining homogeneity. The most troublesome elements, arsenic, antimony, and sulphur, would volatilize at the temperature required, thus keeping the electrolyte clean, and ensuring uncontaminated deposits on the cathode.

After considerable experimentation, the following apparatus was found of service, in dealing with the above problems. The source of heat was a Monitor gas furnace, made by the Buffalo Dental Manufacturing Co. The source of current was a battery of four storage cells, the current being controlled by means of a sliding resistance, composed of 9 mm. arc carbons in connection with a Weston ammeter. The poles of the electrolytic cell were bridged by a voltmeter of the same make.

The electrolytic cell was made from a 20-gram Denver fire clay crucible with a 3 mm. hole bored through the centre of its base. The crucible was then filled half full of plastic fire clay, which was moulded so as to leave a hole, tapering from 3 mm. in diameter at the base of the crucible to 9 mm. in diameter at the surface of the clay. The crucible was then dried and burned. To prepare it for use, a stout iron wire was passed through the hole in the bottom of the crucible, extending about 2 cm. into the conical hole in the clay, and wedged firmly in place with asbestos fibre. The matte to be decomposed was then melted and poured

into the crucible, filling the conical depression, and just covering the fire clay false base.

In operation the iron wire conducted away enough heat to keep the thin column of matte, in the base of the crucible, frozen, thus guarding against any disturbance of results, by the interaction of the metallic iron, with either molten electrolyte or matte.

The electrolyte was then added, and the crucible placed in the furnace, the iron wire extending through a small hole in the base of the furnace and forming the anode connection. The furnace was then fired, and the cathode, which was either a 15 mm. arc carbon or a 9 mm. steel rod, was passed through a hole in the covering bricks, dipping into the electrolyte.

Considerable time was spent in the electrolysis of copper-iron mattes of about the following composition: Copper 50 percent, iron 24 percent, sulphur 26 percent. The electrolyte found most efficacious was a sodium metasilicate. It was found that by controlling the difference in potential across the poles, a very pure copper could be deposited on the cathode, iron remaining in the electrolyte as silicate. When the e. m. f. was increased both iron and copper were deposited apparently as alloy, on the cathode. The sulphur appeared to volatilize entirely at the anode, none remaining in the electrolyte or upon the cathode, with a nickel-copper-iron matte or speiss, the copper could be deposited selectively, and when all the copper had been removed from the electrolyte, the nickel could be removed free from iron, by increasing the e. m. f. It is understood, of course, that the voltage must be kept below the point at which iron silicate is decomposed. In the case of speisses the arsenic and antimony appeared to volatilize quantitatively.

Attempts were made to use halogen salts in place of silicate in the treatment of mattes. It was found, however, that at the temperatures used, chlorides of the alkalies and alkaline earths were both volatile and unstable, while calcium fluoride was not sufficiently fluid. Chloride of sodium, however, was found very useful in the electrolysis of alloys with low fusion points, such as silver-lead.

It would be wearisome and unprofitable to enter into a description of the numerous separations which were made by this method. It might be interesting, however, to note, that a very

sharp separation of silver from lead in a silver-lead bullion was made. This alloy was attacked with a sodium lead silicate electrolyte, the lead being carried over to the cathode, while the silver remained unattacked at the anode.

It is worthy of note that the metals deposited on the cathode by these processes were marked by great adherence as well as purity. Copper when plated upon the 9 mm. steel rod could be removed only by filing. It was possible to hammer, bend, and otherwise deform the steel, without loosening the copper coating.

It will thus be seen that the facts amply bear out the theory, and that by the electrolysis of a fused electrolyte in juxtaposition to a fused anode, separations may be made which are both difficult and costly by the wet method, while there seem to be no concomitant disadvantages in this method.

Pottsville, Pa.,
April 11, 1910.

A paper presented at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 5, 1910, President L. H. Backeland in the Chair.

A NEW PROCESS FOR THE TREATING OF COBALT-NICKEL ORES, RICH IN SILVER AND ARSENIC, BY COMBINED MELTING AND ELECTROLYTIC OPERATIONS

By Camillo C. Cito.

The so-called Canadian cobalt ores have attracted the attention of investors and refiners since their discovery in 1903 because of their unusual richness in silver.

By 1907 the yield of silver from these ores amounted to 5 per cent. of the entire world's supply—but this was obtained mainly from the richest veins; the lower grade ore being thrown aside to await the development of an economical method of extraction.

Besides silver these ores contain nickel, cobalt and arsenic, the latter element often being present to the extent of 40 per cent. The arsenic has proven a serious obstacle in the working of the ore, since, if wasted and the arsenic allowed to escape, it endangers the lives of the community besides entailing a loss of silver equal to about double the amount of arsenic removed. If these volatilized products are condensed expensive chambers must be provided and the condensed products again separated.

The mines are situated in northern Ontario, Canada, to the east of Lake Superior, and with the centre in Cobalt City.

According to the 18th annual report of the Bureau of Mines, Ontario, 1909, Vol. 18, Part 1, the mining camp consists now of forty different mines, which shipped from 1904 to 1907 inclusive, a total of 48,544 tons of ore. The rapid increase in the output is best shown in the fact that in 1908 alone the total shipments amounted to 25,362 tons.

The more important mines of the district are at present: La Rose, Nipissing, O'Brien, Drummond, Crown Reserve, Buffalo, City of Cobalt, Temiskaming, Right of Way, Temiskaming & Hudson Bay, Trethewey, etc. They all ship between 500 and 5,000 tons of ore a year.

The rock consists mostly of greenstone, crossed by granite of a later formation. The ore deposits are found in this granite,

partly mixed with quartz, feldspar, pyrites, magnetite and chlorites.

The veins differ widely as regards thickness as well as disposition of the mass; they contain chiefly the following minerals: Argentite, pyrargyrite, smaltite, cobaltite, erythrite, niccolite. gersdorffite, chloantite, arsenopyrite, etc.

EXPERIMENTS.

The idea suggested itself to try out first the practicability in this special case of all the methods, either wet or dry, already in use for the treatment of similar silver ores. In the following I shall only briefly mention these experiments as all gave more or less unsatisfactory results.

After many failures I succeeded in finding a combined method, consisting of a melting process followed by an electrolytic separation, which I shall describe in detail in the course of this paper. The process is already patented or filed for patent in all the principal countries. (U. S. A. Patents 949,058, 949,059, 949,261).

The experiments described below were made with an ore of the following composition:

4.12%	silver (1200 ozs. per ton)
19.6%	arsenic
11.2%	cobalt
5.7%	nickel
No	lead
No	copper
0.5%	antimony
18.5%	iron and alumina
11.0%	silica
1.7%	calcium oxide
1.9%	sulphur

I. EXPERIMENTS IN MECHANICAL CONCENTRATION.

The ore was ground and passed through a sieve of 200 meshes per square cm. Fifty kg. of ore gave in this way

46 kg.	fines	= 92%
4 "	metallics	= 8%

The distribution of the principal metals was the following:

	Fines.	Metallics.
Silver	2.3%	25.0%
Arsenic	18.5%	32.5%
Cobalt	11.5%	8.3%
Nickel	5.8%	5.1%

As far as the principal metal, silver, is concerned, it can be

seen that about half of it is concentrated in the metallics. The fines, however, are for the same amount poorer and their further treatment therefore less profitable.

II. WORKING BY WET WAY.

The leading idea in these experiments was either to leach the silver out of the raw or roasted ore and collect nickel and cobalt and arsenic in the residues, or to dissolve first nickel-cobalt and arsenic and to recover the silver from the slimes.

All the wet processes known as being in practical use were tried with both raw and roasted ore, at different temperatures and with varying concentration of the dissolving agents, as follows:

(a) *With raw ore:* Leaching with potassium cyanide, hydrochloric acid and sulphuric acid.

(b) *With roasted ore:* Leaching with sodium chloride (Augustin process), sodium thiosulphate (Patera process), sodium-copper thiosulphate (Russel process), potassium cyanide (cyanide process), acids (hydrochloric and sulphuric acid), magnesium chloride, ammonia.

The solutions as well as the residues obtained in the enumerated experiments have been analyzed as far as the principal metals (silver, nickel, cobalt, arsenic) are concerned. Although the experiments were carried out on a small scale, and therefore the conditions for complete reactions were favorable, not in a single case was a satisfactory result obtained. With both raw and roasted ore the silver, on the one hand, did not dissolve completely, even with large quantities of solvent; nickel cobalt and arsenic, on the other hand, when they ought to have dissolved, remained to a large percentage in the residue, especially arsenic, while considerable quantities of silver passed into solution.

The working up of the solutions and the residues would therefore lead to a great many intermediate products and would become very complicated.

III. DRY PROCESSES.

(1) *Roasting Process.*

The object of the roasting experiments was:

(a) To drive out the arsenic by roasting the ore alone or with certain fluxes.

(b) To transform the silver into a soluble compound with the aid of certain fluxes, and to extract it by one of the methods before mentioned.

For the experiments on a small scale the fines passed through the 200 meshes per square centimeter were used; the roasting was done in a small muffle furnace.

When roasting without fluxes at a steadily increasing temperature the ore was dead-roasted after 8 hours. The charge showed a loss of 8 to 12 per cent. of its original weight, corresponding to a loss of silver of from 15 to 24 per cent., while the contents of arsenic changed but little.

In order to prevent the formation of arsenates the same fines were mixed with different amounts of powdered charcoal and roasted for six hours. The roasting losses in these cases varied from 5 to 10 per cent. At the same time the loss of silver varied from 20 per cent. and 30 per cent., with only a trifling loss of arsenic.

With the idea of eliminating the arsenic in the form of sulphide of arsenic, the fines were mixed with raw pyrites and roasted at a slowly increasing temperature for 8 hours. The loss in the weight of the mixture amounted to 8 per cent., according to a loss of 6.3 per cent. silver and 7 per cent. of arsenic.

For a chlorination process the same fines as before were first dead-roasted, then mixed with charcoal powder and roasted a second time in order to decompose the arsenious salts; this product was heated a third time at a dark red heat with a certain amount of sodium chloride. After this third treatment 22 per cent. of the original arsenic contents were eliminated, but at the same time there was a loss of 35 per cent. of the silver.

The products of these roasting experiments were used for testing the different wet methods mentioned above.

The results obtained when roasting the fines in small quantities were fully confirmed by an experiment on a commercial basis. 9,060 kg. of ore was given a preliminary roasting in a reverberatory furnace, then mixed with galena ore and roasted a second time in order to get the material in a lumpy form for subsequent treatment in the blast furnace.

The ore contained 3.77 per cent. silver, equal to 341.56 kg. in the whole charge. The roasted material weighed 8,045 kg., assaying 3.42 per cent., or 275.13 kg. of silver. Therefore the

loss of silver in this roasting amounted to 66.43 kg., or 19 per cent. of the original amount, not including the contents of the flue dust.

At the same time it was ascertained that only a small amount of the arsenic was eliminated. The original 9,060 kg. of ore contained 18.9 per cent. of arsenic, equal to 1,712 kg., while in the roasted 8,045 kg. still 19.2 per cent., or 1,545 kg., of arsenic were found, corresponding to a loss of 167 kg., or 9.8 per cent. of the original amount.

(2) *Melting Process.*

(a) *Melting with Lead Fluxes.*

The ore which had been roasted with charcoal and galena, as described above, was melted in a blast furnace with the usual fluxes, including some lead-bearing material, producing metallic lead, a speiss, a matte and a slag. Although the furnace was running well, the quality of the products was quite unsatisfactory. The lead was very brittle, the speiss could not be cleanly separated from the matte by mechanical means, and the slag was not fluid. The distribution of the principal metals in these four products was as follows:

	Lead.	Speiss.	Matte.	Slag.
Silver	1.78%	0.32%	1.52%	0.013%
Lead		4.	43.	3.3
Copper		0.8	9.	Trace
Arsenic		34.	0.3	
Nickel-Cobalt		41.	5.5	1.5
Sulphur		4.	21.	

Of 299.76 kg. silver contained in the original charge (including the fluxes), 275.03 kg. were recovered in the four products given above. The loss of silver amounts therefore to 24.73 kg., equal to 8 per cent., not including the flue dust. If no account is taken of the loss in the roasting process, the output in silver in the blast furnace operation is fairly satisfactory. The accumulation of nickel and cobalt in the speiss and matte, however, is deficient; indeed, of 1,246 kg. of nickel and cobalt in the original charge, only 319 kg. appears in speiss and matte, corresponding to 25.6 per cent., by far the greater part of these metals passing into the slag.

From the above it results clearly that this kind of ore cannot be melted successfully in a blast furnace with a lead charge, even without considering the loss of silver which already occurs in the

roasting operation. Nickel and cobalt and especially silver are found in all the four products of the furnace in such amounts that the further treatment of these would be very complicated and uneconomical.

(b) *Melting with Copper Fluxes.*

In order to avoid the many products (lead, speiss, matte, slag) which result from melting these ores with lead fluxes, a great number of experimental meltings with copper fluxes were carried out with the intention of producing an alloy containing all the silver, nickel and cobalt and a slag as poor as possible in these metals.

It should be expected that, owing to the small amount of sulphur in the ore, no matte would be formed. The absence of lead is likewise of the utmost importance, and the greatest care is taken that, contrary to the usual processes of treating silver ore, this metal does not enter the material.

To avoid silver losses by roasting, only the raw ore was taken into consideration for these experiments, because it is not possible, as shown in the before-mentioned roasting experiments, to drive out the arsenic to any extent by roasting without losing more or less silver.

The final object of this part of the research consisted in producing an alloy which could be worked up as an anode in an electrolytic bath. At the same time this alloy had to take up as nearly as possible all the arsenic, because, first, as shown before, even small volatilization of arsenic is always accompanied by considerable loss of silver, and, secondly, it is highly important to reduce the escape of the extremely dangerous arsenical fumes to a minimum.

After a number of failures it was found that in order to be successfully worked up as anode, the alloy had to contain the different metals in certain definite proportions.

The amount of copper added has to vary according to the amount of silver, arsenic, nickel and cobalt present in the ore.

As far as the principal metals are concerned, the ores run as follows:

Silver	300—10,000 ozs. per ton.
Nickel and cobalt	10—30%
Arsenic	5—40
Lead	None.

The treatment of the ore consists of two operations, viz.: I, the smelting process; II, the electrolytic process.

I. THE SMELTING PROCESS.

The ore is smelted without any preliminary treatment, such as roasting, etc., in a reverberatory furnace with a calculated quantity of copper and the necessary amount of the usual fluxes.

The addition of the copper practically eliminates arsenic from the fumes in the smelting process because the arsenic is absorbed by the metallic copper.

Only *two* products result from this smelting process:

(1) *An Alloy,* containing, besides copper, all the silver, nickel and cobalt, and nearly all the arsenic. On account of the subsequent electrolytic refining of this alloy, it is important that the different metals composing it, as mentioned before, should be present in a certain proportion, viz., it is necessary that: (a) The percentage of copper be two-thirds of that of the nickel and cobalt, but (b) at least the same as that of the arsenic, and preferably not less than the silver.

The alloy is tapped from the furnace directly into the anode moulds.

(2) *A slag,* containing a very low percentage of silver, nickel and cobalt. This slag can be used to advantage as a flux in the blast furnace, where the last traces of the metals can be easily recovered.

For instance, when melting 174 pounds of ore with the proper amount of copper and the necessary fluxes, no fumes were visible. The result of the melting is to be seen in the following table.

	Canadian Ore Before Melting 174 lbs.	Alloy After Melting 195 lbs.	Slag After Melting 56 lbs.
Silver	6200. oz. p. ton.	5500. oz. p. ton.	29. oz. p. ton.
Arsenic	12.5 percent.	10.75 percent.	Trace.
Nickel and Cobalt	31. "	27.5 "	0.5 percent.
Lead	None.	None.	None.
Copper	"	19.5 percent.	0.5 percent.
Iron	3.5 percent.	0.5 "	7.6 percent.
Sulphur	1. "	1.2 "	
Insoluble	9.64 "		

All the valuable metals pass into the alloy; only a small fraction

of the silver appears in the slag (29 ounces per ton). The data concerning the arsenic are noteworthy: 174 pounds of raw ore containing 12.5 per cent. arsenic, after the melting yields 195 pounds of alloy containing 10.75 per cent. arsenic; allowing for small errors in the analysis, it results clearly from these figures that in melting practically no arsenic has escaped in the fumes.

II. THE ELECTROLYTIC PROCESS.

The different metals of the alloy are separated from the anode in an electrolytic bath by electric current.

A great number of experiments were carried out with alloys of varying composition in small electrolytic baths, in which the utilized anode surface reached 7 square decimeters. Later on, the electrolytic process was tried out in large baths with a utilized anode surface of ½ square meter; the results obtained here were identical with those in the small baths.

The electrolyte consists of a solution of copper sulphate in water, which during the whole electrolytic process contains at least 10 grams of copper and 5 grams of free sulphuric acid per liter.

The cathodes are sheets of pure copper.

The density of the electric current has to be regulated according to the composition of the anodes and electrolyte and according to the temperature.

The temperature is kept most advantageously at 60° Centigrade or higher, and is otherwise regulated by the percentage of arsenic in the anodes.

In case proper conditions prevail, viz., if the electrolyte as well as the temperature and the electric current correspond to the composition of the alloy, the following results will be obtained:

(1) The copper contained in the anode is deposited in the form of pure electrolytic copper on the cathode.

(2) The silver of the anode is *quantitatively* precipitated in the slimes.

(3) All the nickel and cobalt dissolved from the anode remains in solution in the electrolyte.

(4) At the proper temperature the larger part of the arsenic is found dissolved in the electrolyte, the balance going into the slimes with the silver.

FURTHER TREATMENT OF THE DIFFERENT PRODUCTS OF THE ELECTROLYSIS.

(1) The *copper* deposited on the cathode is exceedingly pure. A determination of the copper yielded 99.98 per cent. Cu. The great advantage of this simple, as well as cheap, process is obvious, as the copper originally added as a flux is recovered as a commercial product.

(2) The *slimes,* of course, are rich or poor according to the percentage of silver in the anodes. Under all circumstances the slimes contain all the silver of the anode, as neither in the cathode nor in the electrolyte can traces of silver be determined. The small quantities of arsenic which go into the slimes, together with the silver, can be easily removed by a light roasting or a dissolving process.

For instance, an ore, originally containing 600 ounces silver per ton, 19 per cent. arsenic and 17.5 per cent. nickel-cobalt, yielded slimes of 12,000 ounces silver per ton; while the slimes of another ore than ran 3,500 ounces silver per ton, contained 24,500 ounces silver per ton. These silver slimes can, without any difficulty, be refined in the test furnace by the usual cupellation process. Also, here the advantage of the process can be clearly seen, as the silver, being the principal component of the ores, is extracted in a very simple as well as safe and especially rapid way.

(3) The *electrolyte* containing the whole of the nickel-cobalt and the larger part of the arsenic can be brought up to the following concentrations:

Silver	None.
Copper	10. grams per liter.
Nickel-cobalt	55. " " "
Arsenic	30. " " "

By using insoluble anodes almost all the copper contained in the electrolyte can be precipitated as pure copper on thin lead cathodes. The density of the current has to be lowered according to the decrease of copper in the solution, and at the same time the temperature has to be raised. With a current density of 150 to 200 amperes per square meter and a temperature of 80°-90° C., the copper in the electrolyte can thus be reduced to about two grammes per liter. The precipitated copper is very smooth, and can easily be detached from the lead sheets and used as cathodes in the regular electrolytic baths.

The balance of the copper is advantageously precipitated by sulphuretted hydrogen in the cold, whereby very little sulphide of arsenic is formed. This copper product can be used over as flux. All the arsenic can then be precipitated by sulphuretted hydrogen upon heating as practically pure sulphide of arsenic, which can be placed on the market as such.

Nickel and cobalt can now be recovered, together or separately, by any of the methods usually employed, such as electrolysis or by chemical precipitation.

The principal advantages of this process are:

(1) Utmost simplicity and consequently very low running expenses.

(2) Great rapidity in extracting the most important metals, and especially the silver.

(3) Remarkable safety by reducing to a minimum the danger from arsenic vapors which are liable to develop in the treatment of such material containing a large amount of arsenic.

(4) Direct output of the principal metals, limiting at the same time the forming of by-products.

In contrast to the above described process the methods used at present for the direct production of silver from these ores seem to yield far less satisfactory results.

According to the 18th annual report of the Bureau of Mines of Ontario, 1909, Vol. 18, Part I, "there were three reduction plants in Ontario treating ore from the mines of Cobalt last year, namely, those of the Canadian Copper Company, at Copper Cliff; the Deloro Mining and Reduction Company, at Deloro, and the Coniagas Reduction Company, at Thorold. Through these works there were passed an aggregate of 6,958 tons of ore containing 11,658,008 ounces of silver, of which 8,972,958 fine ounces were recovered, the remainder, 2,685,050 ounces = 23 per cent., being contained in the *speiss* product reserved or exported for further treatment."

Considering, moreover, that probably a great part of the silver produced referred to in this report was shipped in the form of nuggets containing 75 to 85 per cent. of silver, the output appears even less favorable, while in the process which forms the subject of this paper a yield of fine silver of 98 per cent. of the contents of the ore can be directly obtained.

Irvington, N. J., April 18, 1910.

A paper read at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 5, 1910, President L. H. Baekeland in the Chair.

THE ELECTROLYTIC PREPARATION OF MAGNESIUM.

By Samuel A. Tucker and Farel L. Jouard.

From the published descriptions in various text-books, it would appear that the electrolytic preparation of magnesium was a simple thing.

Electrolysis of magnesium chloride in the fused condition is supposed to give the metal and chlorine. From the number of patents that have lately appeared in which other compounds than the chloride of magnesium are named, it would seem as if difficulties were met by others in the preparation of the metal by electrolysis of the chloride.

There are certain factors which influence any electrical process which makes use of molten baths, and they may be summed up as follows:

Current density.

Temperature.

Is the metal produced heavier or lighter than the bath when both are fused?

Is the metal soluble in the constituents of the bath?

What action has the fused bath on the vessels or electrodes?

What means can be employed to keep the metal from combining with products formed at the anode?

ELECTROLYSIS OF MAGNESIUM CHLORIDE.

Preparation of the Bath: The bath should consist of a mixture of magnesium and potassium chloride in molecular proportions. This combination is found in the mineral carnallite, but the mineral itself is unsuitable for the process, as will be shown later. The effect of the potassium chloride is to prevent the ordinary spontaneous decomposition of the magnesium chloride and also to lower the melting point of the bath. In fusing the two chlorides together, it is found desirable to add ammonium chlo-

ride, as this also hinders the decomposition of the magnesium chloride. There are two varieties of magnesium chloride on the market—the crystals $MgCl_2.6H_2O$, and the so-called "fused." The latter appears to contain almost as much water as the former, and it is therefore better to start with the crystallized compound.

A mixture is therefore made of

$MgCl_2.6H_2O$	203 parts
KCl	74
NH_4Cl, sublimed	50

As the magnesium chloride is deliquescent, the resulting fusion will probably not contain the two chlorides in molecular proportions, but experience has shown that this makes little difference in the subsequent electrolysis.

At first, graphite crucibles were used to fuse down the mixture, heating with a gas flame, and also in some cases in a granular carbon electric furnace.[1] If heated by a gas flame, care should be taken to keep the products of combustion from being absorbed by the fusion. This can be accomplished by the use of an asbestos shield with lateral openings for the escape of the gases. One advantage of graphite crucibles for this operation is from the reduction of any sulphates present with elimination of the sulphur dioxide, but graphite seems to be porous to some extent to the fused chlorides, and the yield of fused material is not very good. In the subsequent work, platinum was used, the same precautions being taken to keep out the products of combustion from the blast lamp. The mixture is added in small proportions, allowing time for the steam to escape and also keeping the temperature of the mass low enough to prevent decomposition. When the mass is uniformly melted, the ammonium chloride will have been eliminated; and if the temperature is raised, decomposition of the magnesium chloride will result and the melt will become cloudy. It should therefore be poured into a mould before this stage is reached, and after breaking up, bottled at once. During the fusion, stirring with a carbon rod tends to break up the sulphates.

The yield of fused material is about 50 percent of the fusion mixture. It is important that over-heating of the mass of chlor-

[1] S. A. Tucker, Jour. Am. Electrochem. Soc., **11**, 307 (1907).

ides during fusion be avoided, as experiment showed a loss of 37.7 per cent of magnesium by decomposition and 1.12 percent by volatilization when mixed chlorides were kept at a low red heat for 30 minutes. These results were obtained by analysis of the starting mixture and the subsequent melt.

Electrolysis: The first experiments were conducted on a very small scale, in a 2-inch (5 cm.) porcelain crucible, heated by gas, with small carbon rod for the anode and an iron-wire loop for the cathode. Using 4 to 5 amperes will give the metal in appreciable quantities, the magnesium being retained by the loop.[2] The addition of a small quantity of calcium fluoride is beneficial, as it tends to unite the small globules of metal.

For working on a larger scale, the apparatus shown in the sketch was employed.

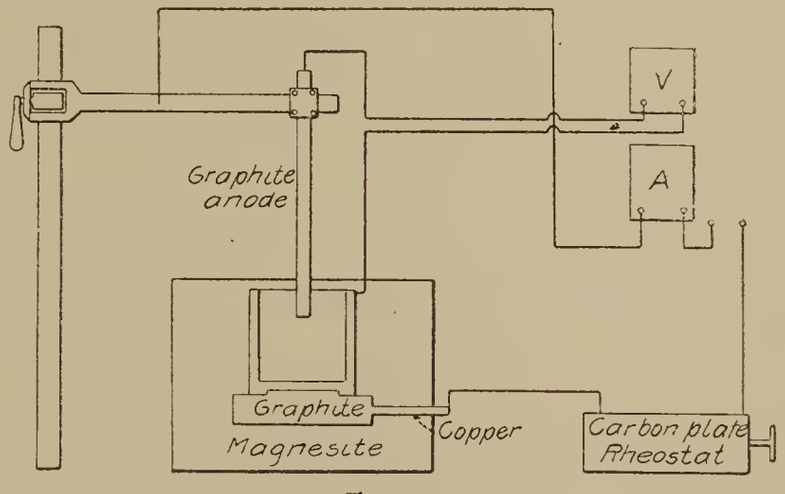


FIG. 1.

The graphite crucible, 2¾ inches diameter, 3½ inches high (6.4 cm. diameter by 8 cm. high), is entirely surrounded by heat-retaining layers of magnesite, and the passage of the current is sufficient to maintain the bath in fusion. The circuit had a capacity of 150 amperes at 30 volts. The whole apparatus was placed in a hood to take off the chlorine, which otherwise is unbearable. This apparatus can be started with a cold charge by drawing an arc with a small carbon rod, but it is easier to add the charge in the molten condition.

It was found best to make the vertical rod (diameter 1.25 inches = 3.1 cm.), the anode and the crucible cathode, though the reverse

[2] S. A. Tucker: Note on preparation of metallic lithium, Jour. Am. Electrochem. Soc., **24**, 10 (1902).

will work fairly well. If the temperature is not raised too high, the metal collects at the bottom and side of the crucible in a spongy form, which is easy to remove from time to time. The sponge is afterwards ignited with an excess of calcium fluoride and some magnesium potassium chloride, so that it unites to a large globule.

Run I:

In this experiment the vertical rod was made cathode, the current used was from 50 to 100 amperes at 10 to 12 volts. The charge was 300 grams of the mixed chlorides with addition of 30 to 50 grams fluorspar. The run lasted 1 hour, but the conditions changed so rapidly that it was impossible to get approximate figures as to energy. The metal was distributed through the bath and was subsequently removed, weighing 6 grams. The accumulation of solids at the cathode hindered any regular working, as it changed the current density at this point. The bath itself tends to become pasty and, finally, this effect is so marked as to stop the process.

Run II:

In this run the poles were reversed, the crucible being made cathode. The charge was the same, weighing 150 grams, with 2 percent of calcium fluoride. Electrolysis was kept up for 10 minutes, using 100 amperes at 12 volts, the temperature being just below red heat. The bath remained clear throughout and metal collected in a semi-spongy mass at the bottom of the crucible. After melting down in another crucible, with an excess of fluorspar, one globule of magnesium was obtained weighing 5 grams.

Run III:

This was made with the vertical electrode as anode. The temperature was kept at a dull red heat, and the metal deposited at the bottom and sides of the crucible in spongy form.

The charge was prepared with particular care, to avoid the introduction of oxy compounds, 10 percent of fluorspar being added. It was poured molten into the crucible, which had previously been heated by the arc.

Time Minutes	Amperes	Volts	Remarks
1.55	50	11	Too hot.
2.00	30	7	
2.05	50	6.5	
2.06	45	10	
2.09	5	9	Removed sponge, bath freezing.
2.14	80	9	Sponge removed.
2.17	118	7	
2.21	35	7	
2.22	100	9	
2.25	110	10	
2.27	60	6	
2.29	65	4	
2.30	65	8	
2.32	60	6	
2.34	65	11	
2.36	50	8	
2.38	60	8	
2.40	100	14	This raised temperature, and
2.43	65	7	melted sponge, but metal
2.44	60	11	seemed to disappear.
2.49	40	11	

51 minutes average 63 amperes.
Grams metal obtained, 11.7.
Theory, 51 minutes, 63 amperes = 24.3.

On melting the metallic sponge with fluorspar flux in a graphite crucible, 11.7 grams of magnesium were obtained. The time being 51 minutes, and the average amperes 63, the theoretical output is 24.3 grams. The ampere efficiency of this run was, therefore, 0.48 = 48 percent.

Run IV:

As it seemed likely that decomposition of the magnesium might take place by allowing it to remain in the electrolytic apparatus, the object here was to make as rapid a removal of the sponge mass as possible.

Time	Amperes	Volts
3.17	95	19
3.08	55	15
3.10	75	9
3.12	60	10
3.14	45	14
3.15	70	14
3.16	55	14
3.17	60	12
3.19	76	12
3.21	88	10
3.23	60	11
3.25	60	15

17 minutes, average 65 amperes.
Charge used, 125 grams.
Metal, 4.76 grams.
Theory for 65 amperes for 17 minutes = 7.15 gm.

This gives a very fair current efficiency, as no record was kept of the time-gaps for removal of the sponge masses.

The voltages given are too high, on account of bad contacts during this run.

Run V:

This had for its object to determine the influence of calcium fluoride on the efficiency of the process. The experiment was conducted as in IV, but the fluorspar was left out.

Time	Amperes	Volts
3.01	40	17
3.04	70	7
3.06	70	5
3.08	70	5

Time, 7 minutes, average, 62 amperes.
Weight magnesium obtained after melting sponge mass = 1.10 grams.
Charge, 100-150 grams.
Theory, 7 minutes at 62 amperes = 3.29 grams.

Run VI:

Was made with an addition of magnesium oxide, in order to determine what influence it had on the efficiency. The run was continued from Run V, with the addition of 4 or 5 grams MgO.

Time	Amperes	Volts
3.17	100	6
3.19	70	9
3.20	65	11
3.22	54	10

10 minutes, average 74 amperes.
Weight magnesium, 1.73.
Theory, 10 minutes at 74 amperes = 6.4 grams.

Comparing these last two runs with Run IV, although the time was short, it would appear that the presence of calcium fluoride is beneficial, and the presence of magnesium oxide is to be avoided.

Run VII:

Was made with fused natural carnallite, for it seemed that if it were possible to use this material it would avoid the trouble and expense of using magnesium chloride.

The carnallite was fused with some ammonium chloride to hinder the formation of oxy-salts in a graphite crucible. The

melting point is considerably higher than when the artificial mixture of the chlorides is used, and this also means that the temperature at which electrolysis is carried on is higher also.

As it proved unsuccessful, as to the formation of metal magnesium, it is unnecessary to give the run in detail. The time was 34 minutes, the current averaged 47 amperes, the voltage 18.5.

Run VIII:

This run was made in a crucible designed by Muthmann.[3] The apparatus consists of a small, conical copper crucible, having a tube or opening at the bottom through which one of the carbon electrodes enters; the sides of the crucible are provided with a copper water-jacket, which congeals the charge so that the copper is protected. The other electrode is a vertical electrode of carbon, which can be adjusted vertically.

The mixed chlorides were added to the crucible cold (see Fig. 2), and were easily melted by a small arc between the electrodes; the upper electrode was made anode and the metal collected at the lower one in one globule, and as it increased in size it would rise to the surface, interfering somewhat with the position of the anode.

Time	Amperes	Volts
11.14	49	8
11.17	54	17
11.20	36	14
11.22	29	15
11.25	26	16
11.27	28	16
11.30	29	16
11.33	29	16
11.37	28	16
11.40	28	16
11.42	28	16

28 minutes, amperes average 33.6.
Yield metal, 3.34 grams.
Theory, 7.12 grams Mg.

The apparatus worked very well, using very small quantities of charge, and on cooling a slight tap at the lower electrode easily detached the charge. As Muthmann has succeeded in using the crucible to advantage in other electrolytic work, it may be as well to mention how the crucible was made:

[3] W. Muthmann, H. Hofer and L. Weiss, Annalen, **320** (2), 231 (1902).

A piece of copper tube, 1¼-inch (3.1 cm.) diameter, 1/16-inch (1.5) mm.) wall, and 4 inches (10 cm.) long, is spun to a cone at one end, beginning with the lathe and finishing on the anvil with hammer. The diameter of the cone at the end was 2⅛ inches (5.3 cm.). Sheet copper is used for the jacket 1/32 inch (0.8 mm.) thick, which can be rolled to cover the outside, with edges hammered over so as to allow for passage of the water; this, and the small copper tubes for entrance and exit of the water, are brazed with silver solder, using the oxy-acetylene flame. The silver solder was made by uniting together metallic silver with half its weight of yellow brass. It is used on copper, with borax glass as flux.

The lower electrode can be of carbon or graphite, and is sep-

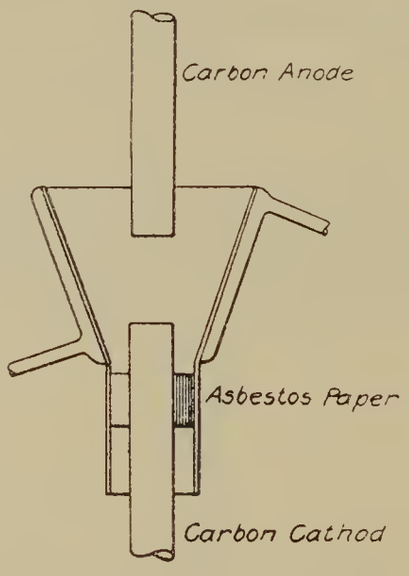


FIG. 2.—Muthmann Crucible.

arated from the crucible by winding asbestos string or paper at this point.

The influence of temperature, current density, and the separation of the magnesium from the chlorine evolved at the anode was investigated by a series of experiments carried on in a small porcelain crucible (see Fig. 3) containing the fused mixed chlorides. The temperature was determined by a thermo couple, and the anode, which was of carbon, was surrounded by a mica shield to prevent the chlorine from diffusing through the bath. The cathode consisted of an iron-wire loop which could be easily varied in the surface exposed. The sketch shows these details.

Changes of temperature were made from 440° C. to 600° and

700° C. At the lower temperature the metal can be removed in the spongy form, at the higher temperature the metal melts and is less easy to recover. The current density at the cathode was raised from 50 to 500 per sq. dm. These changes made but little difference in the current yield of metal, and show that these factors have less influence on the yield than might have been expected. The metal obtained from some of the previous runs was analyzed and found to contain 98.86 percent Mg.

ELECTROLYSIS OF MAGNESIUM FLUORIDE.

Several patents have been taken out with the object of using magnesium fluoride with other compounds, for the electrolytic production of magnesium.[4] The object apparently is to add magnesium oxide to the bath in the same way that the aluminum

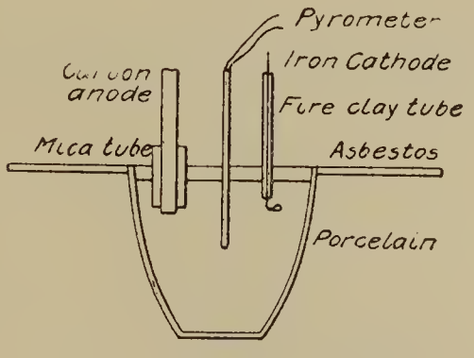


FIG. 3.—Porcelain Crucible.

process is carried on by addition of aluminum oxide to the fluoride of that metal and sodium. Run VIII was carried out in an iron crucible as cathode 2 inches (5 cm.) diameter and 2½ inches (6.3 cm.) high, heated in a small gas blast furnace; the anode was a carbon rod ⅝ inch (1.6 cm.) diameter.

The charge was composed of:

72 parts magnesium fluoride.
36 " lithium fluoride.
36 " calcium fluoride.

The run was made for about 30 minutes, using 15 amperes at from 7 to 9 volts. MgO was added to the extent of 5 percent on the magnesium fluoride, in two portions. On pouring out the

[4] G. O. Seward and F. Von Kügelgen, U. S. Pat. 900961, Oct. 13, 1908, and 880489, Feb. 25, 1908; T. L. Roberts, U. S. Pat. 778270, Dec. 27, 1904.

molten charge, metallic magnesium lined the iron crucible in certain places, but could not be recovered. The quantity was insignificant, and the bath was pasty and some difficulty was experienced with anode effect. In order to render the charge more fluid, the slag was mixed with 15 percent of sodium fluoride, and a run made with it for 30 minutes. The result was about the same, the yield of magnesium being even less than in the former case.

Run IX:

In the next run a change was made in the proportions of the fluorides, which consisted of:

Lithium fluoride,	50	parts.
Magnesium "	25	"
Calcium "	25	"

This was electrolyzed in the same apparatus for 2 hours, averaging 6 amperes and 2.5 volts. In this case not a trace of metal

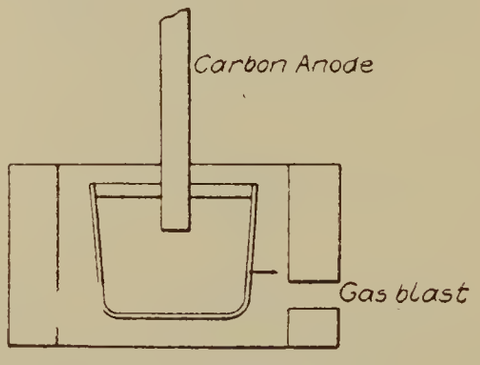


FIG. 4.—Iron Crucible.

was obtained. It seemed possible that the iron crucible might hinder the process, as there seemed to be considerable iron in the slags from these runs, so a carbon or graphite crucible was substituted, using a charge corresponding to the last. This was run for 90 minutes but no metal was obtained. There seems to be a solvent action by such a mixture of fluorides upon magnesium, as was shown by placing a weighted quantity of the metal for a time in the melted fluorides. On examination it was found to have lost weight to the extent of 40 percent, and that remaining was of a very different crystalline appearance. This may account for the absence of any appreciable metal in electrolytic processes making use of a fluoride bath.

A patent was issued[5] which has for its object the preparation of alloys of magnesium, particularly with aluminum, the latter metal being made cathode in a bath consisting of chlorides of magnesium with other additions. The resulting alloy of magnesium and aluminum is then to be electrolyzed, making the alloy anode and obtaining pure magnesium at the cathode. This is carried on in a bath of higher specific gravity, so that the metal will rise to the surface. This was tried, and it may be said that the first operation can be conducted easily, as is shown by the following:

Run X:

Charge of mixed chlorides as in run I. Apparatus, graphite crucible as in same run.

Time	Amperes	Volts
3.18	48	8
3.20	110	20
3.24	83	15
3.27	65	15
3.30	70	17
3.32	55	25
3.38	60	12
3.41	55	15
3.44	73	20
3.49	Stopped.	

Average amperes, 76.
Time, 31 minutes.
Al added, 6.96 grams.
Weight, alloy, 15.03.
Weight, magnesium, 8.07.
31 minutes at 76 amperes = 17.10 grams Mg. Percent ampere efficiency = 47 +

The alloy obtained is a fine crystalline material. The second part of the process, however, is by no means satisfactory. Attempts were made to decompose the alloy in a chloride bath, with the addition of some barium chloride, but it was difficult, if not impossible, to recover a fair proportion of the magnesium.

We do not see any special advantage in such a scheme, as the current efficiency is no better with aluminum present, and the second part is very far from satisfactory. Alloys of copper are easily made in the same way as the aluminum alloys, and show a

[5] F. Von Kügelgen and G. O. Seward, U. S. Pat. 985796, Oct. 5, 1909.

rather better current efficiency; in one experiment an efficiency of 56 percent was obtained.

In conclusion, we would say that magnesium can be obtained by electrolysis of its molten chloride in presence of potassium chloride, preferably in a carbon or graphite crucible, that the bath is troublesome and expensive to prepare and that the current efficiency may run as high as 60 percent. That the presence of MgO is to be avoided and that a small proportion of calcium fluoride tends to consolidate the metal.

In this process changes of current density and that of temperature have comparatively little effect, unless these changes are very great.

Electrolysis of magnesium fluoride and other fluorides as additions for dissolving oxide of magnesium gave practically no metal, and there seems to be direct solution of magnesium in such molten compounds.

Alloys of magnesium with aluminum or copper are easily made by electrolysis with the use of a chloride bath, but they have no special advantage from the standpoint of current efficiency as compared to the process for making pure magnesium.

The electrolytic decomposition of the alloy containing aluminum for the recovery of magnesium was unsuccessful.

Electrochemical Laboratory,
Columbia University,
May, 1910.

A paper presented by C. G. Schleuderberg at the Seventeenth General Meeting of the American Electrochemical Society, at Pittsburgh, Pa., May 7, 1910, President L. H. Baekeland in the Chair.

ELECTRODEPOSITION OF LEAD FROM PERCHLORATE BATHS.

By Frank C. Mathers.

General Statement.

The electrolysis of most solutions of lead salts gives a loose crystalline deposit upon the cathode, which is valueless for refining or plating purposes. Betts has patented[1] the use of a lead fluo-silicate bath containing free fluo-silicic acid and small amounts of gelatine or glue. This bath gives dense, non-crystalline deposits which are commercially valuable.[2] Without the glue or gelatine, loose crystals are formed, such as are characteristic of the nitrate or acetate baths. "Fluo-silicic acid has some specific property not possessed by the nitrate and acetate solutions, and the solid deposit is not the result of the gelatine alone."[3] The addition of gelatine to acetate or nitrate baths does not give satisfactory deposits.[4]

The author[5] has found that a solution of lead perchlorate containing some free perchloric acid and a small amount of an addition substance, such as glue, tannin, licorice, but preferably peptone, works very satisfactorily as an electrolyte for the plating or refining of lead. Cathode deposits may be obtained over an inch in thickness, very smooth and of a density 11.36.

Lead perchlorate, $Pb(ClO_4)_2.3H_2O$, possesses many properties that are ideal for making electro-plating or refining baths. It is "extremely easily soluble in water—one part of salt dissolving in about one part of water."[6] Its great solubility permits the making of solutions of any desired concentration without danger of the crystallization of salts. It is not decomposed by boiling,

[1] U. S. Patent, 713,278.
[2] Betts, Electrochem. Met. Ind., **1**, 407 (1903).
Ulke, Eng. Min. J., Oct 11, 1902.
[3] Senn, Z. Electrochem., April 14, 1905.
[4] Kern, Trans. Am. Electrochem. Soc., **15**, 454 (1909).
[5] U. S. Patent, 931,944 (1909).
[6] Comey, "Dictionary of Solubilities"

by alkalies, by acids or by electrolysis. It is unacted upon by the air, and cannot be reduced by nascent hydrogen—not even by the zinc-copper couple. It can only be decomposed by fusion with sodium carbonate or with sodium nitrate. It does not easily give basic salts. When electrolyzed, it gives dense, solid deposits upon the cathode. The efficiency of corrosion of the anode and of deposition on the cathode is near theoretical, so the composition of the bath remains approximately constant. It does not corrode glass or earthenware vessels, which is an advantage, at least in laboratory work. It conducts the electric current extremely well. Perchloric acid solution has a conductivity near that of hydrochloric acid and greater than sulphuric acid.

	Gram Equivalents per Liter	Percent Composition	Equivalent Conductivity at 18° in. C. G. S. units, $\times 10^{13}$
HCl[7]	0.03	0.109	3581
$HClO_4$[7]	0.0312	0.313	3840
H_2SO_4[7]	0.03	0.147	2673
H_2SiF_6.			5 percent greater than H_2SO_4.[8]

The specific conductivity of perchloric acid of about 35 percent strength is 0.8395[9] (temp. 40°) compared with 0.8257[10] (25°) for sulphuric acid of maximum conductivity (30 percent).

Preparation of Materials.

Sodium perchlorate was used as the starting material for the preparation[11] of the perchloric acid. The solid, dry sodium perchlorate was treated with an excess of concentrated hydrochloric acid. After thorough stirring to break up lumps, the mixture was filtered through asbestos and the residue of sodium chloride was washed with successive small portions of concentrated hydrochloric acid. The filtrate, consisting of a mixture of aqueous perchloric acid, hydrochloric acid and small amounts of sodium perchlorate, was heated on the hot plate until the temperature reached 135°. This completely volatilized the hydrochloric acid with only an insignificant loss of perchloric acid. This aqueous perchloric acid is stable, and is no more dangerous to handle

[7] Whetham, "Theory of Solution," 1902, pages 410, 436 and 437.
[8] Betts, "Lead Refining by Electrolysis," page 21.
[9] Unpublished work by A. F. O. Germann, in this laboratory.
[10] Tower, "Conductivity of Liquids," page 35.
[11] Mathers, Jour. Amer. Chem. Soc., 32, 66 (1910).

than nitric acid. Impurities, such as sodium chloride and sodium chlorate in the commercial sodium perchlorate, are entirely eliminated by this method, and are only objectionable since they act as filling agents, reducing the quantity of perchloric acid that may be obtained. The lead perchlorate was made by neutralizing this aqueous perchloric acid with litharge. There is no need to use white lead for this reaction, except perhaps for the sake of speed in the neutralization of the last small amounts of the perchloric acid. In the preparation of lead fluo-silicate, the fluo-silicic acid must be neutralized with white lead, because litharge is strongly enough alkaline to decompose the fluo-silicic acid into silica and lead fluoride. Perchloric acid is a stable acid that is not decomposed by an alkali. Perchloric acid may also be made by treating barium perchlorate with sulphuric acid. It is necessary to heat the perchloric acid thus obtained until the temperature reaches 135° in order to volatilize the hydrochloric acid, since chlorides are generally present in the commercial material. It is best to use an excess of sulphuric acid, which is precipitated later by the addition of the litharge.

The free perchloric acid in the lead perchlorate baths was determined by direct titration with standard sodium hydroxide using methyl orange as an indicator. The results obtained by this method are approximately correct. The lead was then determined as lead peroxide by deposition from a nitric acid solution.

Beakers were used as electrolyzing vessels.

The lead anodes were cast in graphite molds. They were suspended in the bath by means of copper wires passing through holes. Two anodes were placed in each beaker. The cathode of copper foil was suspended between them. The volume of the bath was 400 c.c. in most of the experiments, although baths containing 2,000 c.c. were used in a few experiments. The solutions were stirred by a current of air during the day and by a current of hydrogen gas at night. The hydrogen generator was so connected that it automatically kept up the current of gas at those times when the laboratory air blast was not running. A very slow current of gas through the solutions seemed to be the best laboratory substitute for the circulation of the electrolyte from tank to tank which is practiced in commercial work. The worst objection to the use of the current of gas is that it stirs

up slime from the bottom of the vessel. Some of these impurities adhere to the cathode. This greatly lowers the purity of the deposited lead.

"Addition Substances."

The lead perchlorate bath does not give good deposits without the use of some "addition substance," except at very low current densities. Numerous experiments were tried, using high concentration of perchloric acid and of lead, but no satisfactory results were obtained.

The addition of small amounts of certain substances to plating and refining baths for the purpose of eliminating or restraining crystals and of improving the density, color and smoothness of the deposits has been a very common practice, or, at least, has been frequently described.[12]

Perhaps the best known example in commercial work is the use of glue in the lead fluo-silicate bath described by Betts. His patent calls[13] for "reducing agents," and he finds that "gelatine, pyrogallol, resorcinol, saligenin, orthoamidophenol, hydroquinone and sulphurous acid" are available. He recommends gelatine because it is the cheapest and gives the best results.

In the course of this work many different addition substances were tried. Tannin, pyrogallol, resorcine, licorice and eucalyptus extract all helped to a considerable extent, but "trees" would form at the corners of the cathode whenever the deposit reached a certain thickness. Tannin might be successfully used if no better substance was available. A high-grade gelatine, which was purchased for use in bacteriology, gave poor results. A commercial grade of glue gave fair deposits. Ordinary commercial glue, which is used in the lead fluo-silicate baths instead of the more expensive gelatine, is a very impure product, containing many things, among which is found a variety of peptone. Analyses[14] of some samples of glue and gelatine show:

	Percent of Gelatine
"Gelatine"	70.95
Superior glue	51.98
Common glue	23.71

[12] Kern, Trans. Amer. Electrochem. Soc., **15**, 441 (1909).
Watts, "Electrometallurgy," 1895, pages 15, 46, 76.
McMillen, "A Treatise on Electrometallurgy," 1890, page 9.

[13] Betts, U. S. Patent, 713,277 (1902).

[14] Allen, "Commercial Organic Analysis," **4**, 479 (1898).

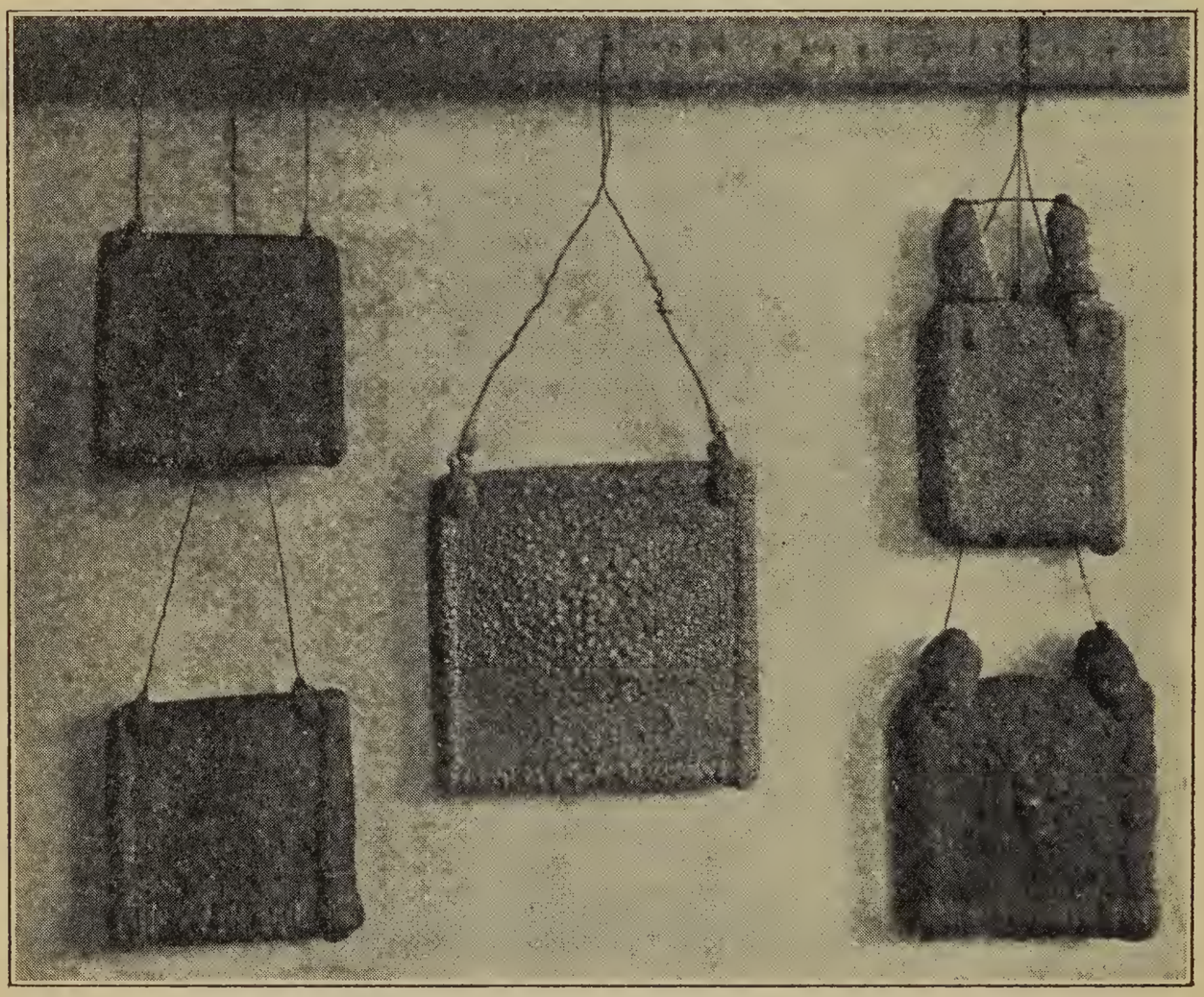
Any decomposition of gelatine or glue by ferments or acids forms gelatin-peptones or gelatones. From the fact that the purest gelatine for bacteriological use showed a less beneficial effect upon the lead deposits than a low grade commercial glue, the conclusion was drawn that some impurity in the glue was responsible for the good work. Glue which had been warmed for several hours with perchloric acid to form gelatin-peptone was tried. The results were uncertain—sometimes good, but more often bad. Acting along the line of this theory, meat peptones were tried. Two different brands of these meat peptones were used—Wittes', probably the purest to be obtained, and a commercial sample from Merck, which was five years old and badly decomposed. Both gave approximately the same results, consequently Wittes' peptone was used on account of its greater convenience and lack of foul odor. Experiments showed that about 0.03 to 0.05 grams of this peptone per 100 c.c. of solution was required. This quantity should be renewed after four or five days, in other words, after the passage of about 25 ampere-hours per 100 c.c. of solution. An excess of the peptone did not have any bad effect. The baths did not become ill-smelling even after long runs. There is some material present in or is formed from the peptone which separates as a pale yellow flocculent precipitate. This precipitate is not always formed, and the conditions for its production are not known. The presence of this precipitate does not interfere with the working of the bath in any way.

Experimental Data.

The current yields are near to the theoretical, as shown by the following table:

Grams of Cu in Coulometer	Amperes per Sq. Dm.	Volts	Cathode		Anode	
			Grams Lead Deposited	Yield Percent	Grams Lead Dissolved	Ampere Efficiency Percent
4.6475	2.8	0.2	15.1526	99.77	15.2111	100.15
1.2350	. .	0.22	4.0277	99.8	4.0828	101.1
0.7290	1.2	. . .	2.3725	99.6	2.4124	101.3
1.4283	2	0.3	4.6580	99.8	4.7027	100.7
1.2054	1.4	0.2	3.7246	99.6	3.9656	100.7

The lead for the anodes had been once refined, but even then a small quantity of slime was formed. Betts has shown[15] that anodes of triple refined lead, which dissolve in the lead fluo-silicate bath without the formation of slime, gave corrosion efficiencies greater than 100 percent. In some of his experiments, the anode corrosion efficiencies, in percent, were as follows: 101.4, 101.8, 101.3 and 101.8. This shows that the free fluo-silicic acid is



This photograph shows the general appearance of lead cathodes from lead perchlorate baths.

gradually changed to lead fluo-silicate. After a time the bath might even become alkaline. This extra loss from the anode is, no doubt, the result of chemical solution by the free acid in the bath. The perchloric acid in the perchlorate bath dissolves lead on open circuit, as shown by the following table. The bath contained 5 percent lead and 5 percent free perchloric acid.

Lead suspended by	Area of lead	Grams dissolved per sq. dm. per 24 hours.
Platinum wire	10.2	0.495
Cotton string	10.2	0.339; 0.414

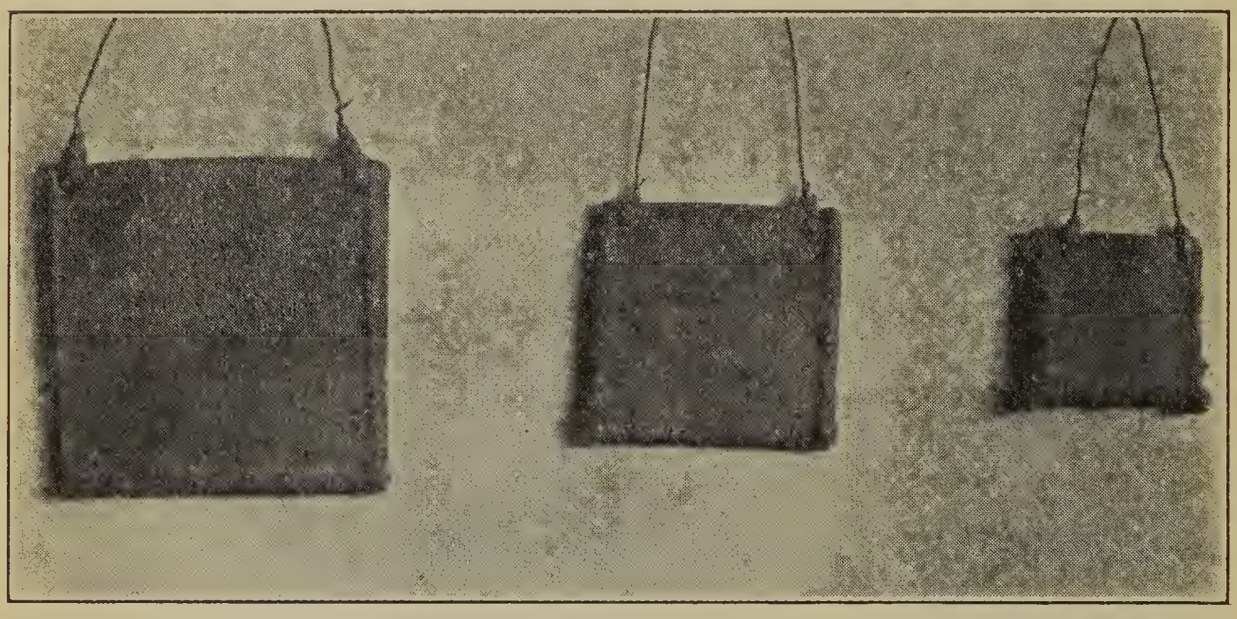
[15] Betts, Trans. Amer. Electrochem. Soc., 6, 67 (1904).

Contact with the platinum wire increased the action, just as would be expected. The finely divided lead in the anode slime would be more rapidly attacked than the massive lead, due to the greater surface exposed and to contact with more positive metallic impurities. The above experiments were made with refined lead, which would dissolve more slowly than bullion. The free perchloric acid which is thus gradually neutralized must be restored. Two methods were tried: When electrolyzing with platinum anodes, the objection is that some lead peroxide is formed on the anode. Of course, the cost of platinum would present difficulties in commercial work. Graphite cannot be used, because it disintegrates during electrolysis. A simpler method is to add the required amount of sulphuric acid to a portion of the electrolyte. Lead sulphate is precipitated and perchloric acid remains in solution. The filtrate is returned to the bath. This diminution in acidity is not rapid. It is greater, of course, with baths containing large amounts of acid. This may be seen from the following table:

Percent of Acid in the Bath	Loss of $HClO_4$ in Percent, Per Day
1.6	0.025
4.5	0.07
4.9	0.05

Current Density: Many things have an effect upon the practicable current density. A high current density is favored by concentrated solutions, high percent of free acid, large amounts of peptone, and good stirring. With 5 percent lead, 5 percent perchloric acid, 0.05 percent peptone and enough stirring or mixing of the solution to prevent large differences in concentration between the top and the bottom, a current density of from 2 to 3 amperes per sq. dm. (18 to 27 amperes per sq. ft.) gives good deposits, as shown by the accompanying photographs. With lower current densities, less care need be taken with stirring, proper spacing of the electrodes, acidity and quantity of peptone. For plating purposes, low current densities are recommended. With 0.4 amperes per sq. dec., fair deposits may be obtained from baths containing only 0.2 percent free perchloric acid. With higher current densities, these neutral baths give poor deposits, even when large amounts of peptone are used.

Voltage: The relation between concentration of the solution, current density and fall in potential or volts is shown in the following table. These measurements were made upon baths which had been running for several days and which were giving excellent deposits. The anodes were of ordinary commercial lead from a plumber's scrap pile. Two anodes were used—one on each side of the cathode. The anodes had been made purposely smaller than the cathodes to prevent, as much as possible, the thickening of the cathodes at the edges.



Showing the Effect of Current Density.
1 amp. per sq. dec.; 2 amp. per sq. dec.; 4 amp. per sq. dec.; 5.4 percent lead; 4.5 percent perchloric acid; 0.05 percent peptone.

Experiment 1.

Composition of the bath: 4.5 percent $HClO_4$, 5.4 percent lead, and 0.05 percent peptone. The distance between anode and cathode was 2. 2. cm. Volume of the solution was 400 c.c.

Amperes Per Sq. Dm.		
Anode	Cathode	Volts
3.2	1.6	0.21
4.0	2.0	0.27
5.6	2.8	0.38
8.0	4.0	0.55

Experiment 2.

Composition of bath: 6.1 percent $HClO_4$, 7.13 percent lead, and 0.05 percent peptone. The distance between anode and cathode was 4 cm. Volume of solution was 800 c.c.

Amperes Per Sq. Dm. Anode	Cathode	Volts
1.0	0.21	0.08
2.2	0.45	0.15
2.6	0.55	0.18
3.8	0.8	0.25
4.2	0.9	0.26
5.0	1.6	0.30
6.2	2.	0.34

The results were the same with new anodes or with anodes that were covered lightly with slime containing enough mercury to give a bright color.

Purification Results.

The purity of the deposited lead which is obtained by the electrolysis of this bath is shown by the accompanying analyses of the different products.

	Cu. Percent	Sb. Percent	Pb. Percent	As. Percent	Ag. Percent	Bi. Percent
Experiment (1)						
Slime	1.89	37.56	6.49	. .	6.29	30.83
Bullion . . .	0.18	1.5	. . . .	0.24	1.48	0.87
Refined Metal	0.005	0.004	99.984	none	0.003	0.004
Experiment (2)						
Slime	83.9	. . . .	4.05	. . . .	. . . .	. . .
Bullion . . .	0.45	. . . .	. . . .	. . . .	. . . .	. . .
Refined Metal	0.0007	. . . .	. . . .	. . . .	. . . .	. . .
Experiment (3)						
Slime . . .	. . .	. . . .	1.1	. . . .	91.0	. . .
Bullion	. . . .	. . . .	. . . .	. . . .	1.84	. . .
Refined Metal	. . . .	. . . .	. . . .	. . . .	none	. . .

In these experiments, the copper, antimony, silver, arsenic and bismuth were added to the bullion in order to obtain a low-grade material. The anodes were suspended with platinum wires to avoid a slight contamination with copper which resulted when copper wires were used. The copper connecting wires, while not attacked very rapidly, nevertheless become appreciably smaller after being used for a long time in making connections to the anode. This might be avoided if the copper was cast into the anodes and not merely hooked through holes. The fact that these copper wires, in contact with the anodes, are only very

slightly attacked gives a striking visible proof that lead may be easily purified from copper.

The analyses show that the refined lead from very impure bullion contains only minute quantities of impurities. These impurities[16] are, for the most part, due to the method of circulating the solution by a current of gas. This stirs up the slime from the bottom, some of which adheres to the cathode.

The slime contains only a small amount of lead. This is important, because it simplifies the subsequent treatment for the recovery of the valuable metals which are in the slime.

Loss of Perchloric Acid.

Some of the electrolyte is always mechanically trapped or held within the metal of the cathode. The loss of perchloric acid caused by this was determined by fusing portions of the cathodes with sodium nitrate. This treatment decomposes the perchlorate into chloride.[17] The chlorine was determined by Volhard's method, and was calculated into perchloric acid. The results are:

	Gms. of Cathode Used	Gms. of Chlorine in terms of Perchloric Acid	Percent Loss of Perchloric Acid
Very smooth cathode . . .	25.	0.0041	0.018
Very rough cathode . . .	18.	0.0035	0.02

This represents a loss of about 0.4 pounds of perchloric acid per ton of lead deposited.

The perchlorate baths, which had been used for months, did not give any test for chlorides with silver nitrate. This shows that there is no loss of perchloric acid by slight reduction.

The slime, even after careful washing, contains some of the perchlorate of the bath. One sample of slime showed 1.1 percent of perchloric acid. This result includes the chlorine from chlorides calculated to perchlorate. Some chlorine had come, perhaps, from the dust and fume of the laboratory. These chlorides, during electrolysis, would unite with the silver of the anode and thus remain in the slime. The total loss of perchloric acid in the slime represents a loss of 1.1 pounds per ton of lead refined if the bullion contained 5 percent of impurities.

[16] Kern, Trans. Amer. Electrochem. Soc., 6, 39 (1904).

[17] Mathers, Jour. Amer. Chem. Soc., 32, 66, (191·).

Thus the total loss of perchloric acid from unpreventable sources amounts to about 1.5 pounds per ton of lead refined. This does not include any loss from leaky tanks and pipes or careless handling.

Precautions.

Chloride and barium salts must be absent. A bath that has been giving good deposits will form very bad "trees" if a quantity of hydrochloric acid or some barium perchlorate is added to it. The injurious action of these substances was accidentally discovered from the fact that some baths, made from reagents containing these impurities, would not give good deposits. There are, perhaps, other salts that would act injuriously, but only those mentioned above have been tried.

SUMMARY.

This paper describes experiments with the lead perchlorate plating and refining bath. The properties of lead perchlorate, which are of special value in a plating or refining solution, are:

1. Great solubility.

2. Cathode deposits which are smooth, dense and free from "trees."

3. Approximately theoretical corrosion of the anode and deposition upon the cathode.

4. Absolute stability under all conditions to which it is subjected in a plating or refining bath.

5. No polarization from the formation of lead peroxide on the anode.

6. Very high electrical conductivity.

The bath should contain about 5 percent of lead, 2-5 percent of free perchloric acid, and 0.05 percent of peptone. A current density of from 2.3 amperes per sq. dm. (18-27 amp, per sq. ft.) may be used. The peptone is gradually used up, and after about four days a quantity equal to the original amount should be added. The free acid, which is very slowly neutralized by chemical solution of the lead, must be restored by the treatment of a suitable portion of the solution with the right amount of sulphuric acid.

This precipitates lead sulphate and leaves perchloric acid in solution. The filtrate is to be returned to the bath. The bath gives excellent purification, the cathode being about 99.98 percent pure. The deposit is smooth, coherent, and has a density of 11.36. As a plating bath, the lead perchlorate solution works exceptionally well on account of the absence of "trees" or loose crystals on the edges, even when the deposits reach a thickness of an inch. The bath shows no deterioration with use, and gives as good deposits after two months as at the beginning if the concentration, acidity and the required amount of peptone are maintained.

From the successful results obtained by the above method on a laboratory scale, I see no reason why it cannot be applied on a commercial scale especially for the plating of lead, since the deposits are of exceptional smoothness and are entirely free from "trees" or loose crystals on the edges or points.

University of Indiana.
April, 1910.

DISCUSSION.

MR. A. G. BETTS *(Communicated)*: A correction should be made of the ratio of the conductivity of sulphuric and fluosilicic acids. If the reference is consulted the ratio will be seen to be 62:57, or a difference of about 9 percent.

Probably perchloric acid is not entirely stable in the presence of metal electrodes, and especially in that of metal sponge or anode slime. It would be interesting to know whether or not appreciable quantities of metallic impurities go into solution from chemical action of the acid on the anode slime.

The favorable result obtained when using perchloric acid as basis of the lead-depositing electrolyte should be ascribed to the fact that it is a strong, *i. e.*, strongly dissociating acid, and practically non-oxidizing, at least as far as the cathode surface is concerned. No good lead deposit has been obtained when the basis of the electrolyte is a weakly dissociating acid.

DR. J. W. RICHARDS: I regard this paper as a very important addition to our knowledge of the electrometallurgy of lead, and it

is particularly interesting as showing some more of the possibilities of addition agents. I am convinced that the possibilities of addition agents in various fields of electrolysis is by no means exhausted, in fact, have just begun to be investigated.

I was informed yesterday of an electroplating process being worked on a commercial scale in which the addition of a small amount of an organic addition agent, one entirely different from any that has so far been proposed, permitted the increase of the current density to three times its former strength and produced a plating of even better quality. The simple use and discovery of this addition agent increased the capacity of the plant 200 per-cent. I am not at liberty of giving further details of the method, but I state this to show some of the latent possibilities of addition agents and the value of research upon their applications.

Mr. J. S. Goldbaum: A very recent German paper has advised the use of lead boro-fluoride as electrolyte, also with a recommendation of the use of gelatine or peptone. This is a very complete and interesting paper.

A paper presented at the Seventeenth General Meeting of the American Electrochemical Society, at Pittsburgh, Pa., May 7, 1910, President L. H. Baekeland in the Chair.

THE ELECTRODEPOSITION OF PLATINUM—II.

By W. J. McCaughey and Harrison E. Patten.[1]

Introduction.

In a previous paper[2] it was found expedient to use an aqueous solution containing 2 grams potassium chlorplatinate and 10 grams citric acid in 100 c.c. water, in depositing platinum. The high concentration of citric acid gave a better deposit. When hot concentrated potassium chlorplatinate solution which has once been subjected to electrolysis is again electrolyzed, it becomes alkaline near the cathode; and, as the KOH concentration increases within ten to fifteen seconds after starting electrolysis, there is formed a dark cloud of finely divided platinum. This cloud spreads rapidly through the electrolyte, and must be removed by filtration to secure an adherent coating of platinum; the deposit obtained in presence of this cloud is crusty.[3] If the anode be rotated, stirring the solution, the formation of this cloud is delayed, and a fine deposit of platinum obtained; but with stationary electrodes this cloud of fine platinum is soon formed again, thus rendering it practically impossible to secure a deposit of the metal under these conditions.

Platinum is deposited electrolytically in several forms, depending upon the conditions:

1. A silvery deposit, non-adherent, except in thin layers, peeling off in flakes—favored by low current density, below hydrogen-evolution point.

2. A dark, greasy ("crusty") deposit, acting much like a layer of oil to prevent contact with electrolyte. This greasy deposit and the cloud of finely divided platinum in solution appear

[1] Published by permission of the Secretary of Agriculture.

[2] "The Electrolytic Deposition of Platinum," Trans. Am. Electrochem. Soc., **15**, 523 (1909).

[3] The word "crusty" as used here means that the deposit forms a coating much like a crust of grease.

at the same time, *i. e.*, when the content of platinum in solution has decreased considerably.

3. A black, steely deposit, hard and very adherent.

4. A hard, crystalline deposit of square plates or scales formed from concentrated solution when the current density is too high to give deposit No. 3. Crystalline deposition favors a porous coat, and the metal underlying "sweats" through.

In the present paper the conditions given above were duplicated, and in addition anode and cathode discharge potentials were taken to assist us in interpreting the differences observed in the deposits of platinum and the effect of citric acid.

Experimental.

Solutions (aqueous):

1. Ten per cent. citric acid.
2. Two per cent. $K_2Pt\ Cl_6$.
3. Two per cent. $(NH_4)_2Pt\ Cl_6$.
4. Two per cent. $K_2Pt\ Cl_6$, carrying ten per cent. citric acid.
5. Two per cent. $(NH_4)_2\ Pt\ Cl_6$, carrying ten per cent. nitric acid.

Electrical measurements: The single potentials at anode and cathode during electrolysis of the above solutions were measured by momentarily interrupting the current and balancing the e. m. f. of discharge potential plus an Ostwald half cell (N/10 KCl), against a known e. m. f., using a d'Arsonval galvanometer as zero instrument. Detailed diagram and description of connections and instruments will be found in a previous paper.[4] The current was read on a milliammeter, and the temperature of the solution taken from time to time. A platinum dish served as cathode, and permitted the deposit of platinum to be weighed; the anode was of polished platinum, 10 sq. cm. in area. The solution was heated to 75°-80° C. before electrolysis, and then electrolyzed, no attempt being made to maintain its temperature. This was done because the previous work on deposition of platinum was carried out in this manner, and the present study is an attempt to re-produce these conditions and study the single potentials which then obtained. When the solution temperature

4. "On the Electrolytic Reduction of Nitric Acid," Trans. Am. Electrochem. Soc., 12, 334 (1907).

is plotted as a function of the time a smooth curve is obtained for each solution, and the curves for the different solutions are fairly close to each other, in actual value, during the major portion of the period of electrolysis.

Fig. 1 shows the anode and cathode polarization of citric acid solution as given in Table I. The structural formula $C_3H_4.OH-(COOH)_3$ indicates the complex nature of the oxidation and reduction processes to be expected when it is subjected to electrolysis. For example, one, two or three of the acid groups, COOH, might be reduced at the cathode to aldehyde groups, which in

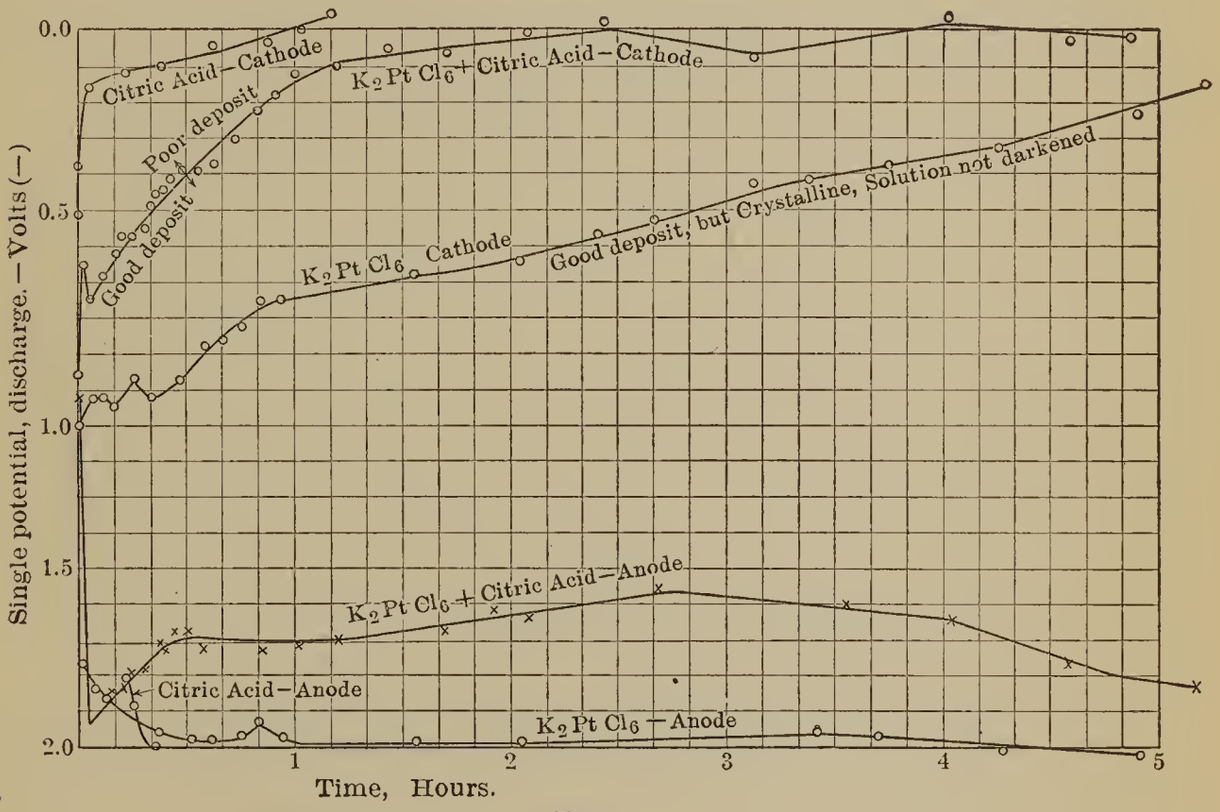


FIG. 1.

turn might be further reduced to alcohol groups, or might condense to form more complex bodies, or polymerize. At the anode we may have liberation of CO_2 and of unsaturated hydrocarbons, or formation of ethereal salts. Then, by diffusion from anode to cathode and the converse, the possibilities of interaction of these bodies are further increased. At present, time is not available to examine definitely the products of this electrolysis, but the single potential measurements indicate that citric acid at the cathode serves to depress the potential below the value given by hydrogen against a platinum cathode; this means that hydrogen is reacting upon the citric acid, probably with the

formation of aldehyde. The anode polarization (the short anode curve in Fig. 1) lies considerably below the potential of oxygen—1.4 volts, indicating the use of oxygen by the citric acid.

When K_2PtCl_6 alone is electrolyzed (Table II), the cathode polarization is low, as would be expected from the single potential of platinum, starting at —1.0 volt and tending upward as the solution is stripped of platinum, and then the polarization of hydrogen comes more and more into play—Fig. 1, central curve. The deposit obtained in this particular case was good, and, as usual with *fresh* K_2PtCl_6 solution, the solution was not darkened by the formation of a dark cloud of platinum. At the anode the polarization shows the normal trend of chloride solution during electrolysis, from —1.73 volts to nearly —2.0 volts.

When citric acid is added to the K_2PtCl_6 solution, Table IV, the cathode polarization lies between that for citric acid solution and that for K_2PtCl_6 alone; see Fig. 1. A good deposit of platinum is obtained during the first 30 minutes, after which the deposit grows crystalline; the cathode potential rises as this deposit deteriorates. The anode single potential here is at first very near that of citric acid alone or of chlorine alone, but soon rises to a value near that of oxygen, though it still is lower than that of oxygen. A strong rancid odor of butyric acid gave indication of the decomposition of the citric acid. It is altogether likely that chlorinated bodies are formed.

Fig. 2 shows the cathode and anode polarization of a two per cent. solution of $(NH_4)_2PtCl_4$ alone; see Table III. A good adherent deposit is obtained while the cathode potential remains low; then when hydrogen begins to come out the polarization rises and the deposit grows crystalline, and finally, after 163 minutes, a cloud is formed; up to 30 minutes the solution was acid. It is seen that the change is confined to the cathode; the anode curve shows the normal polarization of a chloride under these conditions. The permanent cathode polarization at 104 minutes has the same value as the discharge potential later, when the cloud forms in solution.

Using $(NH_4)_2PtCl_4$ + citric acid, Table V, the cathode potential (Fig. 2) is slightly above that of the $(NH_4)_2PtCl_6$ alone (as was the case with the K_2PtCl_6 and the K_2PtCl_6 + citric acid). The first deposit is good and adherent, but soon begins

to go crystalline, although a cloud does not form. It appears that a bad deposit may be obtained when no cloud of fine platinum has appeared. Citric acid prevents cloud formation, but a cloud is not formed in its absence in fresh solutions.

It is evident that presence of citric acid does not give a lower cathode potential than that which obtains while platinum is depositing in the absence of citric acid. The function of citric acid appears to be to maintain the solution acid. The alkaline solution furthers the formation of the fine platinum cloud, which may be thrown out of suspension upon the cathode and serve

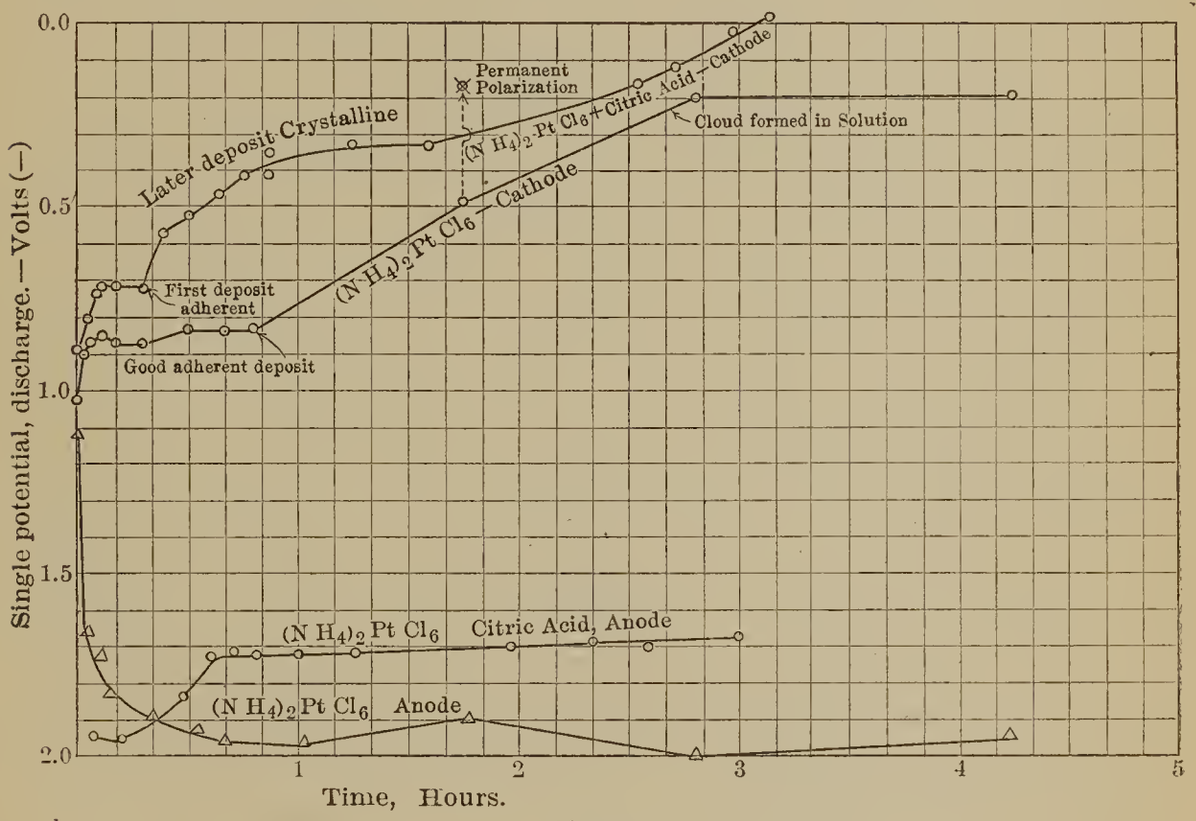


FIG. 2.

as nuclei for deposits of larger crystals. The reduction of citric acid to aldehyde may further influence the form of the deposit. This requires further study.

The cloud of fine platinum does not form immediately in a *fresh* solution of K_2PtCl_6 or of $(NH_4)_2PtCl_6$, unless the current density be too high.

If a chlorplatinate solution which has been electrolyzed be regenerated by addition of solid chlorplatinate salt and again subjected to electrolysis, the cloud of fine platinum is soon formed and the deposit is poor. But if a drop or two of concentrated hydrochloric acid be added to 100 cubic centimeters of solution,

the cloud formation is delayed and a good deposit is formed. The objection to the use of mineral acid for this purpose is that it attacks the underlying metal, and, too, the deposit of platinum is likely to become crystalline before a satisfactory coating can be obtained. When, however, citric acid is used, the plating solution may be regenerated many times by addition of K_2PtCl without cloud formation, and good deposits of platinum obtained. The solubility of the chlorplatinate salts of potassium and ammonium is so slight that the actual quantity of platinum contained in the plating solution is very small. A saturated solution of K_2PtCl_6 at about 85° contains two per cent. of the salt. This is the reason for working with a hot solution. One of the authors[5] obtained a deposit of platinum from a cold unsaturated solution of K_2PtCl_6 in weakly acid solution (H_2SO_4) using a very low current density. A carbon anode was used and all the platinum deposited from solution upon the platinum dish so completely as to be indistinguishable from the metal of the dish.

It should be noted that even in the solution containing citric acid, the deposit of platinum becomes poor after some 25 to 30 minutes of electrolysis. In practice, a good thick deposit of the metal is obtained by repeatedly plating for ten-minute periods. After each treatment, the deposited metal is dried and buffed. The solution is regenerated by adding K_2PtCl_6 before each treatment, and will serve for some twenty to thirty treatments, after which it may be further regenerated by adding about 10 drops of concentrated hydrochloric acid, and will then serve for five or six more deposits of platinum.

The solution is then discarded and the platinum recovered as follows: The old solution is made alkaline with potassium hydroxide (KOH), or sodium hydroxide (NaOH) and a little alcohol ($C_2H_5.OH$) added, and heated to about 60°-70° C., and the platinum is deposited as a fine black cloud which flocculates and settles; a strong odor of aldehyde is in evidence. This is filtered, washed with aqueous hydrochloric acid and dissolved in aqua regia (by volume 3 parts conc. HCl to 1 part conc. HNO_3) and evaporated to dryness as $H_2PtCl_6.6H_2O$, a deliquescent body. This substance dissolved and treated with NH_4Cl or KCl will give K_2PtCl_6 or $(NH_4)_2PtCl_6$, to use in the plating solution.

[5] H. E. Patten, at Madison, Wis., in 1904.

TABLE I.

Electrolysis of 10 percent aqueous citric acid.

Area of platinum anode, 30 sq. cm.
Area of platinum cathode, 110 sq. cm.
Volume of solution, 100 c.c.

Period Minutes	Current Amperes	Single Potential Discharge		Temperature (Solution) °C
		Anode Volts	Cathode Volts	
0	0.000	—0.511	—0.372	77
0	0.120	. . . .	. .	. . .
2	0.100	. . . .	. . . .	. . .
3	0.120	. . . .	. . . .	. . .
5	. . .	. .	—0.159	51.5
8	. . .	—1.780	. .	47.0
13	. . .	—1.810	—0.117	42.0
19	0.100	. .	. .	. . .
21	. .	—2.005	. . . .	. . .
22.5	. . .	. . . .	—0.103	. . .
32	. . .	. . . .	—0.087	. . .
38	0.220	.	—0.045	. . .
47	. .	—1.965	. . . .	. . .
52	. . .		—0.030	28.0
57	. . .	—1.995	—0.003	. . .
69	0.670	. .	—0.003	. . .
75	. . .	—1.940	+0.068	. . .
82	. . .	. . . .	+0.068	. . .
90	. . .	. . . .	+0.055	. . .
95	1.000	. . .	. . .	. . .
98	. . .	—1.995	+0.068	. .
107	1.050	—2.025	+0.083	. . .
110	1.350	. . . .	.	. . .
115	1.350	. . . .	+0.068	. . .
122	1.350	—2.025	+0.068	. . .

TABLE II.

Deposition of platinum from 2 percent aqueous K_2PtCl_6 solution.

Area of platinum anode, 10 sq. cm.
Area of platinum cathode, 110 sq. cm.
Volume of solution, 100 c.c.

Current constant at 0.120 ampere.

Period Minutes	Single Potential Discharge		Temperature (Solution) °C
	Anode Volts	Cathode Volts	
			80
(Current on)	—1.753	—1.100	. . .
3	—1.753	. .	69
4	. . . .	—1.024	. . .
4.5	—1.838	.	
6	. . . .	—1.025	60
8	—1.866	. . .	. . .
9	. . . .	—1.040	. . . .
15	—1.893	—0.976	44.6
20	. . .	—1.026	39.5
22	—1.950	. . .	. . .
28	. .	—0.971	35
31	—1.965	. .	33.5
36	. . . .	—0.886	31.5
37	—1.977	. . . .	. . .
40	. . . .	—0.856	30.4
45	—1.967	—0.814	29.2
50	—1.937	—0.757	28.0
56	—1.967	—0.743	26.8
93	—1.981	—0.686	23.4
122	—1.981	—0.644	22.5
144	—1.951	—0.574	22.3
161	—1.967	—0.532	22.1
187	—1.951	—0.433	21.8
202	—1.951	—0.419	21.7
224	—1.965	—0.378	21.7
256	—2.009	—0.321	21.5
294	—2.025	—0.223	21.4
312	—2.031	—0.148	21.5
336	—2.037	—0.148	21.6

Current off 0.7193 gr. Pt. deposited.
Deposit, fair to good; crystalline. No darkening of solution.

TABLE III.

Deposition of platinum from 2 percent aqueous $(NH_4)_2\ PtCl_6$ solution.

Area of platinum anode, 10 sq. cm.
Area of platinum cathode, 110 sq. cm.
Volume of solution, 100 c.c.

Current constant at 0.120 ampere.

Period Minutes	Single Potential Discharge		Temperature (Solution) °C
	Anode Volts	Cathode Volts	
0	—1.106	—1.014	78
0	. . .	. . .	63
2	—1.666	—0.901	. . .
4	. . . .	—0.873	58
5	—1.723	. . . .	56.5
7	. . . .	—0.859	54.5
9	—1.823	. . .	50.5
10	. . . .	—0.873	.
18	. . . .	—0.873	40.5
20[1]	—1.893	. . . .	. . .
30	. . .	—0.831	. . .
31	—1.922	. . .	33.5
39	—1.953	—0.831	31
47	—1.953	—0.831	29.3
61	. .	—0.689	. .
62	—1.953	. . . .	. . .
104	. . . .	—0.490	23.2
106	—1.893	. . . .	. . .
131	—1.638[2]	—0.178[2]	23.0
(Current off	9 minutes.)		
159	—2.007	— .192	22.7
246	—1.949	— .192	. . .

[1] Solution now has acid reaction.
[2] Permanent polarization, current off.

Current off, 0.4589 gr. Pt. deposited.
Deposit good, light in color, but later the deposit is finely crystalline, and may be brushed off easily.
As the solution cools down, yellow crystals of $(NH_4)_2PtCl_6$ separate out on the anode.

TABLE IV.

Deposition of platinum from 2 percent aqueous K_2PtCl_6 solution, containing 10 percent citric acid.

Current constant at 0.120 ampere.

Period Minutes	Single Potential Dis.		Temp. (Solution) °C	Condition of	
	Anode Volts	Cathode Volts		Solution	Deposit
0	—1.021	—0.980	75.0		
0	. . . .	. . . .	. . .		
1.5	—1.765	—0.643	. . .		
3.5	—1.935	. .	60.0		
4.5	. . . .	—0.768	. . .	Clear	
5.5	. . . .	. . . .	55.0		
7.5	. . . .	. . . .	52.5		
8.5	. . . .	—0.685	50.8		
9.5	—1.850	. . . .	49.0		
11.0	. . . .	—0.629	47.3		
12.0	—1.823	. .	45.0	Clear	
12.5	. . . .	—0.573	44.0		
15.0	. .	—0.573	41.6		
15.5	—1.795	. . . .	40.8		
16.5	. . . .	—0.573	39.8		
17.5	. . . .	—0.549	38.8		
18.5	—1.782	. . . .	38.1		
19.5	. . . .	—0.487	37.5		
21.5	. . . .	—0.461	35.9		
22.0	—1.699	. . . .	. . .	Clear	
24.5	. . . .	—0.447	34.2		
25.0	—1.720	. . . .	33.9		
26.5	. . . .	—0.405	33.2	Clear	
27.0	—1.668	. .	32.9		
29.0	. . . .	—0.390	31.9		
29.5	—1.668	. . . .	31.8		
30.5	. .	—0.404	31.6		
31.5	—1.668	. .	30.9		Dark[1]
32.0	. . . .	—0.405	30.7		
33.5	—1.711	—0.405	29.9		
37.5	—1.711	—0.377	29.5		
43.5	—1.720	—0.306	27.5		
49.5	—1.720	—0.222	26.4		
53.5	—1.720	—0.179	25.6		
59.5	—1.711	—0.123	24.6		
72.5	—1.699	—0.095	23.7		
95.5	—1.699	—0.067	22.8		
115.5	—1.668	—0.067	22.2		
128.5	—1.614	—0.017	22.0		
138.5	—1.643	—0.011	22.0		
154.5	—1.614	+0.017	21.6		
183.5	—1.556	. . . .	21.6		
209.5	—1.629	+0.073	21.6		
234.5	—1.600	+0.088	21.6		
263.5	—1.643	+0.031	21.6		
298.5	—1.769	—0.025	21.6		
314.5	—1.810	—0.011	21.6		
339.5	—1.839	—0.011	21.6		
359.5	—1.820	+0.029	21.6		
361.5	Current off. 0.6532 gr. Pt: deposited.				

Area of platinum anode, 10 sq. cm. Area of platinum cathode, 100 sq. cm. Volume of solution, 100 c.c.

[1] The deposit was black and apparently not crystalline up to 30 minutes; the subsequent deposit was dark and greasy and non-adherent. Toward the end of experiment rancid odor of butyric acid was strongly in evidence. After 1 hour, deposit was very bad; 3 hours practically completed the deposition. On cooling K_2PtCl_6 did not separate out. No cloud formed in solution.

TABLE V.

Deposition of platinum from 2 percent aqueous $(NH_4)_2PtCl_6$ solution, containing 10 percent citric acid.

Area of platinum anode, 10 sq. cm.; of platinum cathode, 110 sq. cm. Volume of solution, 100 c.c. Crystals of $(NH_4)_2PtCl_6$ separated at anode.

Period Minutes	Current Amperes	Single Potential Discharge		Temperature (Solution) °C
		Anode Volts	Cathode volts	
0	0.000	—0.888	—0.888	70
0	0.113	. . . .	—0.803	57.5
5	. . .	—1.943	. . .	50
6	. . .	. . . .	—0.722[1]	. . .
7.5	. . .	. . . .	—0.715	45.8
8	0.125	. . . .	. . . .	. . .
10	. . .	. . . .	—0.715	43
11	. . .	—1.956	—0.722	42.5
18.5	. . .	. . . .	—0.722	. . .
23.5	. . .	. . . .	—0.572	32
28	0.110	—1.843	. . . .	32
30	. . .	. . .	—0.529	
31	. . .	. . . .	—0.529	. . .
36	0.110	—1.728	.	29.8
38	. . .	. . . .	—0.471	. . .
43	. . .	—1.713	. . .	28.6
44.5	. . .	. . . .	—0.416	. . .
49	. . .	—1.713	. . . .	27
51	. . .	. . . .	—0.416	27
59	. . .	—1.713	. . . .	. . .
60	. . .	. . . .	—0.359	. . .
74	0.110	. . .	—0.330	25
75	. . .	—1.713	.	. . .
95	. . .	. . . .	—0.331	24.1
118	. . .	—1.699	—0.245	23.8
140	. . .	—1.685	—0.218	23.5
153	. . .	. . . .	—0.164	. . .
154	0.110	—1.699	. . . .	. . .
163	. . .	. . . .	—0.121	. . .
178	. . .	. . . .	—0.023	. . .
179	. . .	—1.672	. . .	. . .
188	. . .	. . . .	+0.033	23.5
Current off				

[1]No gas escaping from cathode.

Deposit black, very adherent, shading into crystalline deposit around the edges, where the platinum crystals easily brushed off. Under the microscope these are seen to be square plates of a steely color.

Bureau of Soils,
United States Department of Agriculture,
April 10, 1910.

A paper presented at the Seventeenth General Meeting of the American Electrochemical Society, at Pittsburgh, Pa., May 7, 1910, President L. H. Baekeland in the Chair.

THE CONDUCTIVITY AND ELECTROLYSIS OF CUPROUS CHLORIDE SOLUTIONS

By M. deKay Thompson and E. R. Hamilton.

1. Introduction.

The following investigation had for its object a study of the refining of copper in a cuprous chloride solution. Only work of a preliminary nature has been completed at the present time, but, as the investigation has been temporarily interrupted, it seemed best to publish the results obtained.

The only advantage that could be expected in refining copper from a cuprous chloride solution is that 96,600 coulombs of electricity would deposit 63.6 grams of copper, assuming 100 percent efficiency, in place of half this quantity, which is obtained in the acid copper sulphate solution universally employed in copper refining. If the resistance of the cuprous solution were the same as the sulphate solution, it is evident that only half the power now consumed for refining copper would be required. In 1904 the maximum available energy in the ten electrolytic refineries in the United States was 12,700 horse-power,[1] which since then has doubtless been considerably increased. At $20 a horse-power year the cost of the power used in 1904 in the United States to refine copper would be $254,000. If the refining could be done with a chloride solution of the same conductivity as the sulphate solution, there would have been a saving of $127,000. This possibility seemed, therefore, a question worthy of some consideration. One stage of Hoepfner's process of winning copper directly from its ores consisted in electrolyzing a cuprous chloride solution.[2] This, however, was not successful, and no attempt seems to have been made to refine copper in this solution.

In order to show that cuprous chloride could be used in place of the sulphate solution, it would be necessary to show that

[1] Titus Ulke, "Die Elektrolytische Raffination des Kupfers," p. 43 (1904).
[2] Zeitschr. f. angew. Chem. (1891), p. 160.

approximately twice the copper can be obtained from a cuprous chloride solution, that the deposit adheres to the cathode firmly, that the resistance of the solution would not be materially greater than that of the sulphate solution, and that the copper obtained is of as high a purity as is usual in electrolytic refining. There is also the question of whether the anode would dissolve evenly and of how concentrated the impurities that go in the solution may become before a regeneration of the solution is necessary.

2. Conductivity.

The first point taken up was the conductivity of cuprous chloride solutions. This salt is only slightly soluble in water, but dissolves in a solution of another chloride. Sodium chloride was the salt used in the following experiments for dissolving the cuprous chloride. The following table shows the solubility of cuprous chloride in sodium chloride.[3]

Concentration of Sodium Chloride	Quantity of Cu_2Cl_2 Dissolved		
	At 90°	At 40°	
Saturated Solution	16.9 percent	11.9 percent	8.9 percent at 11°
15 Percent Solution	10.3 "	6.0 "	3.6 " at 14°
5 Percent Solution	2.6 "	1.1 "	. . . . .

The solutions for conductivity were made by adding more than enough dry cuprous chloride to saturate sodium chloride solutions of different concentrations. The cuprous chloride was prepared by the method given in Blanchard's "Inorganic Preparations." The solutions were kept under an atmosphere of carbon dioxide, while adding the cuprous chloride, to prevent oxidation. Solutions containing less than 20 grams of sodium chloride to 100 grams of water remained clear and white after saturating with cuprous chloride, but those containing more than 20 grams of sodium chloride to 100 grams of water increased in turbidity with increasing concentration and were of a greenish-yellow color.

The following conductivity measurements were made on solutions containing 15, 20, 25 and 30 grams of sodium chloride to

[3] Comey's Dictionary of Solubility (1896).

100 grams of water. These solutions were heated to 60° and 70° C., saturated with cuprous chloride, poured into small beakers, and the conductivity determined with small "dipping electrodes" as the solutions cooled off. As the solutions cooled the excess of salt precipitated.

TABLE I.

Conductivity of Cuprous Chloride Solutions.[4]

Saturated Solutions of Cuprous Chloride in Solutions of					
15 Grams NaCl to 100 Grams Water		25 Grams NaCl to 100 Grams Water		30 Grams NaCl to 100 Grams Water	
Temp.	Conductivity	Temp.	Conductivity	Temp.	Conductivity
52.7	0.2245	52.0	0.2916	47.5	0.2925
51.5	.222	51.0	.289	46.2	.2795
50.7	.222	49.0	.282	45.8	.280
49.9	.2195	48.1	.2724	45.5	.280
49.2	.215	47.2	.2712	45.0	.278
48.4	.2125	46.1	.2665	44.5	.2745
48.0	.2108	45.7	.2635	43.7	.2733
47.3	.2080	45.0	.264	43.0	.271
46.0	.206	44.5	.261	42.6	.269
45.3	.198	43.9	.258	42.2	.269
40.0	.1952	43.5	.253	41.6	.264
37.0	.1808	42.6	.252	41.2	.263
35.0	.179	41.7	.252	40.8	.258
34.0	.169	41.2	.252	39.9	.256
33.0	.1668	40.0	.2465	39.4	.259
31.3	.166	31.0	.218	38.8	.2545
29.5	.159	30.0	.2158	38.5	.250
28.0	.154	28.4	.209	37.6	.247
26.5	.149	27.7	.2015	34.5	.238
25.2	.146	27.3	.1998	32.3	.237
24.5	.144	27.0	.199	31.0	.231
23.2	.138	26.2	.1975	29.3	.221
22.3	.137	26.0	.196	28.9	.2195
21.0	.1352	25.5	.192	27.9	.2115
20.2	.1319	23.6	.1892	26.7	.208
		22.2	.1842	26.4	.2045
		21.3	.1805	26.2	.202
		20.7	.1750	25.1	.198
		20.2	.1735	24.6	.196
				24.1	.197
				23.5	.1925
				22.0	.186
				21.5	.188
				21.0	.1865

[4] The units are reciprocal ohms for a cube whose edge is one centimeter in length.

Plotting these data and taking the values from the plot for 50°, 40° and 25°, the following table is obtained:

TABLE II.

Conductivity of Cuprous Chloride Solutions.

Temperature	Saturated Solutions of Cuprous Chloride in Solutions of		
	I 15 Grams NaCl in 100 Grams Water	II 25 Grams NaCl in 100 Grams Water	III 30 Grams NaCl in 100 Grams Water
25°	0.145	0.193	0.200
40°	0.188	0.245	0.258
50°	0.217	0.281	0.298

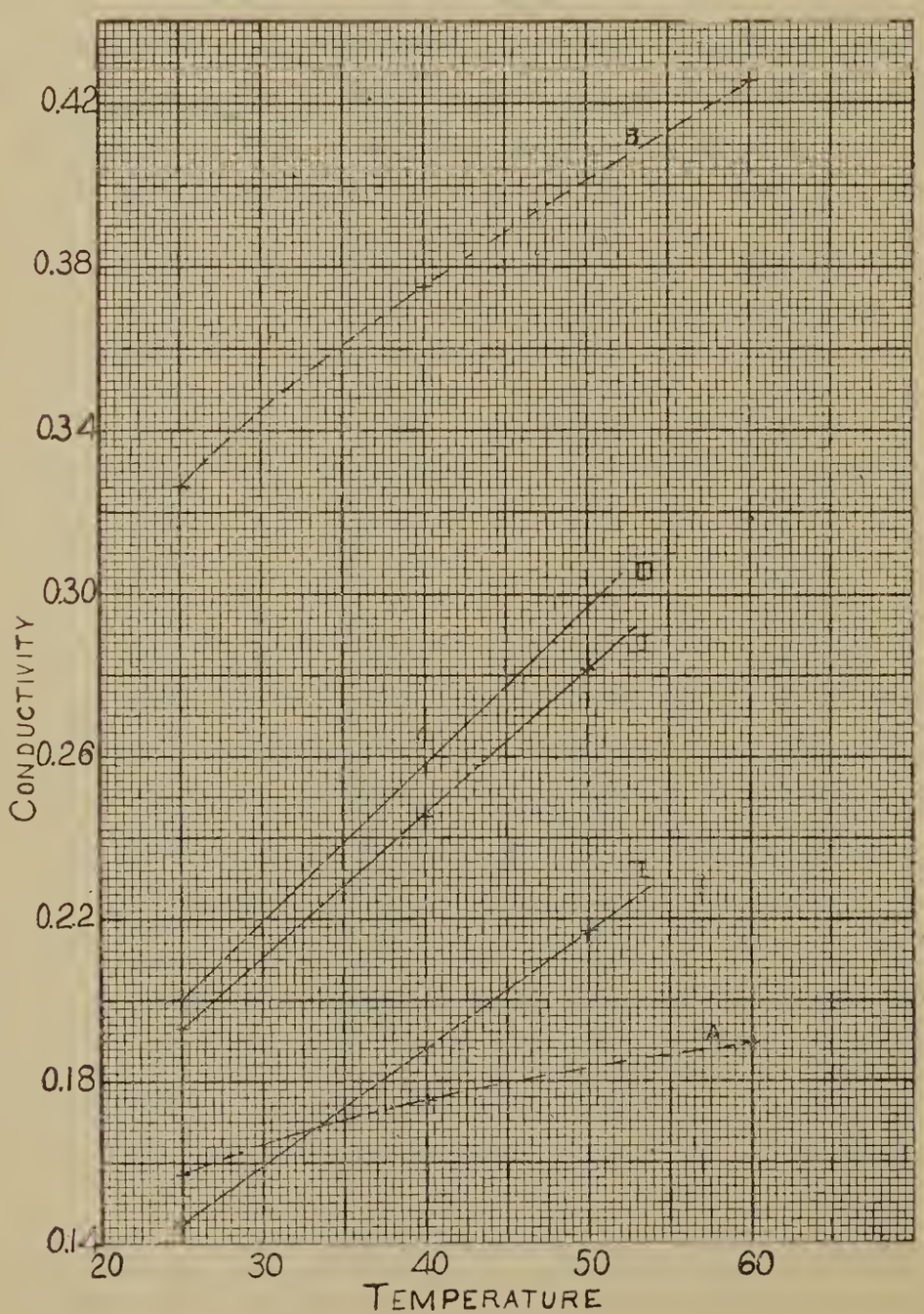


FIG. 1. Conductivity of NaCl solutions saturated with Cu_2Cl_2 (I, II, III), and of $CuSO_4$—H_2SO_4 solutions (A, B).

The results are given in Fig. 1. A comparison with the conductivity of pure sodium chloride shows that the saturation with cuprous chloride has lowered the conductivity of the solutions. For example, the conductivity at 25° of a solutions made by dissolving 25 grams of sodium chloride in 100 grams of water is 0.225[5] reciprocal ohms, while after saturating it with cuprous chloride it has fallen to 0.145. This can be counteracted by the addition of a small amount of hydrochloric acid, which at the same time clears up the turbidity. The following measurements were made of the conductivity of a solution made by dissolving 25 grams of sodium chloride in 100 grams of water, saturating with cuprous chloride and adding the indicated amount of hydrochloric acid of specific gravity 1.188 at 21.7°.

TABLE III.

Conductivity of Acidified Cuprous Chloride Salt Solutions at 21.8° C.

Cubic Centimeters of HCl added to 100 c.c. of solution	Conductivity
1.115	0.195
1.595	0.204
2.08	0.206
2.52	0.215
3.26	0.224
3.66	0.230
4.32	0.237
4.81	0.242
5.55	0.251

For the sake of comparison, measurements were also made on the conductivity of acid copper sulphate solutions. According to Ulke,[6] the solutions used in practice always contain between 12 and 20 percent of crystallized copper sulphate and between 4 and 10 percent free sulphuric acid, and are used between 50° and 60° C. In order to get limiting values of the conductivity two solutions were made up, one containing approximately the

[5] Calculated from data in Kohlrausch and Holborn's "Leitvermögen der Elektrolyte," p. 145 (1898).

[6] "Die Elektrolytische Raffination des Kupfers," p. 42 (1904).

minimum amount of acid and salt, the other the maximum amount. Solution A was made by dissolving in one liter 135 grams of Baker and Adamson's copper sulphate and 42.5 grams of sulphuric acid of specific gravity 1.837 at 22.6° C., corresponding to 40 grams of pure acid. The resulting solution has a specific gravity at 22.2° of 1.077. The content of free acid was therefore 3.75 percent and that of sulphate with five molecules of water was 12.5 percent.

Solution B was made by dissolving in one liter 220 grams of copper sulphate and 117 grams of the above acid, corresponding to 110 grams of pure acid. The resulting solution had a specific gravity at 21.2° of 1.199. The content of free acid was therefore 9.2 percent and of the salt was 18.3 per cent. The conductivity measurements were made in a cell whose constant was determined by means of a normal solution of potassium chloride. The cell was placed in a thermostat and the temperature kept constant to a few hundredths of a degree.

The following measurements were obtained.

TABLE IV.

Conductivity of Acid Copper Sulphate Solutions.

Temperature	Solution A	Solution B
25° C	0.1573	0.3260
40° C	0.1752	0.3754
60° C	0.1895	0.4252

These results are plotted in broken lines in Fig. I.

3. *Electrolysis.*

Cohen and Lenz[7] have shown that at room temperature 1.81 times as much copper can be obtained in cuprous chloride solutions as in sulphate solutions and that at 70° the ratio can be increased to 1.99. It was also found that the concentration had an effect on the current efficiency. The best result was in a

[7] Zeitschr. f. Elek. 2, 25 (1895).

solution containing 5 grams of copper to one liter, any change in the concentration being accompanied by a reduction in the ratio.

Before studying the effect of impurities, it was thought best to carry out a few electrolyses in a pure solution, such as was used in the conductivity determinations. Two small cells containing a solution of 25 grams of sodium chloride in 100 grams of water saturated with cuprous chloride, and copper electrodes, were connected in series with a copper coulometer. The cuprous chloride cells were covered with a layer of liquid paraffine. In one cell the solution had turned to a deep brown, while in the second it remained nearly white. On electrolyzing with a current density of 2 amperes per square decimeter at room temperature the efficiency in the dark-colored cell was 78.2 percent and in the other 95.9 percent, 100 percent being taken as twice the amount of copper deposited in the coulometer. The anodes were eaten away badly at the surface of the liquid. This always took place in neutral solutions where there was no stirring. There was also a corresponding heavier deposit on the upper part of the cathode, as though the liquid conducted better at the top than at the bottom of the cell. Coehn and Lenz obtained a similar result. There was a great tendency to form crystalline trees of copper, so that where the current density was not uniform the tree would grow to the anode and short-circuit the cell. Stirring the solution prevented uneven solution of the anode and produced an even deposit on the cathode of a darker color than obtained with a sulphate solution. During the electrolysis the solutions tended to oxidize and form a green scum on the surface. The scum and the turbidity of the solutions can be removed by the addition of a little hydrochloric acid. In order to see what effect the acid has on the electrolysis, to one portion of a solution of 25 grams of sodium chloride in 100 grams of water saturated with cuprous chloride just enough hydrochloric acid was added to clear the turbidity; to a second portion hydrochloric acid of specific gravity 1.188 was added in the proportion by volume of 4.6 of acid to 100 of solution. These were placed in cells with copper electrodes, and were connected in series with a coulometer and electrolyzed with current density of 0.75 amperes per square decimeter. The cuprous chloride solutions were stirred by passing in hydrogen.

The results are given in the following table:

TABLE V.

Electrolysis of Acid Cuprous Chloride Solutions.

	Cuprous Chloride		Copper Sulphate
	No. 1	No. 2	
Voltage at start	2.0	0.18	0.36
Voltage after 2 hours . . .	3.0	0.50	0.46
Voltage after 3 hours . . .	0.84	0.20	0.35
Gain in weight	2.68 grams	3.05 grams	1.66 grams
Current efficiency	80.6 percent	91.6 percent	100 percent

The deposits in cells 1 and 2 were both smooth and adhered firmly. After the electrolysis the solutions stood in contact with the anodes for 48 hours. After 24 hours the first solution had a bright green scum on the surface and had become turbid, while at the end of 48 hours the second solution had only become a little darker in color. The copper was badly corroded at the surface of the liquid in Cell Number 1, while in Cell Number 2 it was scarcely corroded at all.

SUMMARY AND CONCLUSIONS.

1. It was shown that the conductivity of cuprous chloride solution can be made as high as that of the solutions ordinarily use in copper refining, by the addition of hydrochloric acid.

2. At room temperature a current efficiency of 90 percent of the theoretical can be obtained when the solutions are acidified. The presence of free acid is therefore beneficial both in increasing the conductivity and the current efficiency.

3. These results show, as far as they go, that there would be a reduction of 50 percent in the power required for copper refining in using an acid cuprous chloride solution.

Electrochemical Laboratory,
Massachusetts Institute of Technology,
April 14, 1910.

A paper presented at the Seventeenth General Meeting of the American Electrochemical Society, at Pittsburgh, Pa., May 7, 1910, President L. H. Baekeland in the Chair.

COMPARISON OF RAPID ELECTRO-ANALYTICAL METHODS.

PART I.—THE DETERMINATION OF COPPER.

By Francis C. Frary and Andrew P. Peterson.

As a contribution to the rapid electro-analytical determination of the metals, Stoddard[1] and L. S. and R. C. Palmer[2] have recommended the use of a platinum-gauze cathode and currents of 5 to 8 amperes, without rotation or stirring of the electrolyte, depending on evolved gases and convection currents for the necessary agitation. Inasmuch as the above-mentioned authors concluded that the use of the gauze cathode was the principal factor in the success of the method previously described by one of us[3], and that rotation or stirring of the solution was unnecessary, it seemed worth while to repeat this work, especially since, as pointed out in the discussion of the paper of the Messrs. Palmer, the experimental evidence adduced was, in a measure, inconclusive. In this paper only the determination of copper will be discussed; work upon other metals is in progress, and will be reported later.

The general plan pursued has been to work out for each method the conditions giving, in the minimum time, complete precipitation and a deposit of the proper weight. The solutions used were prepared from the salt obtained by the recrystallization of Kahlbaum's C. P. copper sulphate. The solutions remained perfectly clear, depositing no sediment, and were free from iron. For each analysis, 50 c.c. of the solution used were measured out with a pipette, observing all the usual precautions. Solution A was standardized by precipitation on a gauze cathode from a solution containing 8 to 10 drops of concentrated nitric acid, by connecting with one cell of a storage battery and electrolyzing for about 18 hours. Precipitation was complete and the deposit of proper character. Results found: Copper 0.5046, 0.5047 gm.

[1] J. Am. Chem. Soc., **31**, 385 (1909).
[2] Trans. Am. Electrochem. Soc., **15**, 489 (1909).
[3] Frary, J. Am. Chem. Soc., **29**, 1592; Z. angew. Chem., **20**, 1897 (1907).

Solution B, standardized in the same way, gave copper 0.5456 and 0.5454 gm. By evaporation in platinum and ignition it gave CuO equivalent to 0.5457 gm. copper. On solution of this residue a slight opalescence was obtained with barium chloride, but on filtering, no weighable amount of sulphate was found. The value of the solution was assumed to be 0.5456 gm. copper. Solution C was standardized electrolytically as in the case of Solution A, the results being 0.4885 and 0.4887 gm. copper. Solution D was made by diluting 50 c.c. of Solution B to fill a 500 c.c. flask, and calculating its value from the calibration ratio of the flask and pipette.

At the close of the electrolysis, the electrodes were slowly raised from the electrolyte, while the deposit was rapidly rinsed off by a stream of distilled water. The cathode was then rinsed with re-distilled alcohol and dried at 105°. The solution and washings, amounting to less than 150 c.c., were tested with hydrogen sulphide. Tests on similar volumes of known solutions showed that 0.1 mg. Cu gave a slight brown coloration, while 0.2 mg. gave a very distinct brown color.

Preliminary experiments were first made to determine the best electrolyte for use. It was hoped to use an electrolyte free from nitric acid, as this acid is well known to retard the deposition of copper. But determinations in such a solution, even on adding sulphuric acid or ammonium sulphate, gave results which, although concordant, were uniformly 1 to 2 mg. high. Ammoniacal solutions likewise gave poor deposits, and the resistance of the solution was so high as to produce an inconvenient amount of boiling during the electrolysis. Ammoniacal potassium cyanide, with the least possible amount of the cyanide, as recommended by Smith[4], was tried. Fine deposits were obtained, but they were uniformly from 0.2 to 0.9 mg. too heavy. With one sample of cyanide, which was probably impure, results 2 to 3 mg. high were often obtained. Suspecting that, contrary to the statement of Smith, the anode was being attacked, it was weighed at frequent intervals, and the loss calculated in terms of ampere-hours passed. This loss, in three series of experiments lasting respectively 100, 70 and 60 minutes, with a current of 5 amperes, amounted to 0.051, 0.025 and 0.040 mg. per minute. This loss appears to be independent of the amount of copper deposited and

[4] "Electro-analysis," 1907 edition, p. 77.

of the excess of cyanide, as in the above experiments the amounts of copper deposited were 1.6, 1.1 and 0.25 gm. respectively, while in an experiment lasting 20 minutes, in which the usual amounts of cyanide and ammonia were used, but no copper, a total loss of 0.9 mg., or 0.045 mg. per minute was found. In this last experiment the cathode gained in weight 0.5 mg. As Gooch and Read[5] found that silver deposited from a potassium cyanide solution occluded some cyanide, several of these precipitates, after the usual washing and drying, were boiled with water and the water tested for cyanide. As in the case reported by Gooch and Read, this water gave a slight precipitate with silver nitrate; another portion treated with ammonia, ammonium sulphide, hydrochloric acid and ferric chloride gave a red coloration, confirming the presence of cyanide. This method was therefore given up as unsatisfactory, and recourse had to the use of the smallest possible quantity of nitric acid.

TABLE I.

Precipitation during magnetic rotation (gauze cathode), from HNO_3 electrolyte. Current, 5 amperes, except No. 7 (6.5 amp.) and No. 8 (6 amp.). Volts, 10-12. Temperature at start, 65° to 70° C. All precipitates compact, adherent and of good color. Concentrated acid used.

No.	Sol.	Wt. found gm.	Error (mg)	Time (min.)	Copper Left	Acid (Drops)	
						HNO_3	H_2SO_4
1	A	0.5032	—1.4	11	Trace	8	8
2	A	0.5036	—1.0	12	Trace	8	8
3	A	0.5037	—0.9	15	None (*b*)	7	(*a*)
4	A	0.5038	—0.8	15	None (*b*)	8	8
5	A	0.5050	+0.4	17	None	7	(*a*)
6	A	0.5028	—1.8	11	Trace	3	8
7	B	0.5441	—1.5	11	Trace	3	8
8	B	0.5459	+0.3	12	None	4	8
9	A	0.5047	+0.1	13	None	3	8
10	A	0.5042	—0.4	13	None	5	8
11	A	0.5046	±0.0	13	None	4	(*a*)
12	B	0.5455	—0.1	13	None	3	8
13	B	0.5456	±0.0	14	None	3	8
14	B	0.5454	—0.2	15	None	3	8
15	B	0.5453	—0.3	15	None	4	8
16	B	0 5456	±0.0	16	None	3	8
17	B	0.5454	—0.2	20	None	4	8
18	B	0.5454	—0.2	20	None	4	8
19	B	0.5457	+0.1	22	None	5	8

(*a*) 2 gm. ammonium sulphate used.
(*b*) Test not delicate as it was made in volume of 350 c.c.

[5] Am. J. Sci. (1909), 544.

Table I shows the results obtained by the use of magnetic rotation and varying quantities of nitric acid. Determinations Nos. 1-5 show that if 8 drops of nitric acid are used, about 17 minutes are required, while Nos. 6-16 show that with 3 to 4 drops the time may be reduced to about 13 minutes. Nos. 17-19 show that longer electrolysis does not injure the determination. It seems to be quite important to heat the solution to about 70° C. before electrolyzing.

Table II.

Precipitation on gauze cathode from *cold* HNO_3 electrolyte. Analyses 1-6 with magnetic rotation, 7-11 without rotation. Current, 5 amperes, except No. 7 (6 amp.). Volts, 10-12. Concentrated acids added. Precipitation complete in all cases.

No.	Sol.	Wt. Found Gm.	Error Mg.	Time Min.	Acid (Drops)		Character of Deposit
					HNO_3	H_2SO_4	
1	B	0.5469	+1.3	15	3	10	Firm, slightly dark
2	B	0.5465	+0.9	14	3	8	Slightly dark
3	B	0.5458	+0.2	15	5	8	Perfect
4	B	0.5464	+0.8	16	5	8	Perfect
5	B	0.5473	+1.8	14	4	8	Slightly dark
6	B	0.5477	+2.1	15	4	8	Perfect
7	A	0.5100	+5.4	21	8	8	Dark, bulky
8	A	0.5046	±0.0	17	8	8	Dark red
9	A	Not weighed	. . .	18	4	4	Spongy, flakes lost
10	A	0.5054	+0.8	. . .	9	8	Spongy
11	B	0.5465	+0.9	20	8	8	Slightly dark

Table II shows the results obtained when starting with cold solutions, the first six determinations being made with a rotating solution, the others without rotation. A decided tendency toward high results is to be noted, and the precipitate is likely to be dark. The area of the electrode seems to have a very slight influence upon the character of the precipitate. Two cathodes were used in these determinations. The first was home-made, of gauze, having 20 meshes per cm.; it weighed about 8 gm. and had an effective area of about 69 sq. cm.[6] The other was of the ordinary manufactured type, of gauze having 15 meshes per cm.; it weighed 13.5 gm. and had an area of about 58 sq. cm. It was noted that the deposit on the lighter cathode was always of a

[6] Calculated from the formula $S = 2\pi\, dlb\sqrt{n}$, which appears to be more accurate than that given by Smith, $S = 2\pi\, d\sqrt{nlb}$. (Electro-analysis, p. 72.)

better color, and showed less tendency to become spongy. It would appear that the current density at the cathode, though less important than in the old style of determination, still has some influence.

Table III.

Precipitation on gauze cathode without rotation, from HNO_3 electrolyte. Current, 5 amperes, except Nos. 6 and 9 (6 amp.). Volts, 10-12. Temperature at start, 60° to 70°. Concentrated acids added.

No.	Sol.	Wt. Found Gm.	Error Mg.	Time Min.	Copper Left	Acid (Drops)		Character of Deposit
						HNO_3	H_2SO_4	
1	D	0.0521	—2.4	9	Much	8	6	Dark and spongy
2	D	0.0537	—0.9	11	Much	10	6	Good
3	D	0.0547	+0.1	12	None	10	6	Good
4	2D	0.1098	+0.6	12	None	10	6	Good
5	D	0.0551	+0.6	14	None	10	6	Dark
6	A	Not weighed	. . .	10	Much	3	8	Dark, flaky
7	A	0.4888	—6.8	15	Much	7	8	Good
8	A	0.5048	+0.2	17	None	7	8	Good
9	A	0.5062	+1.6	18	None	8	8	Brown
10	A	0.5047	+0.1	19	None	8	8	Good
11	C	0.4888	+0.2	20	None	6	6	Good
12	C	0.4887	+0.1	20	None	6	6	Good
13	C	0.4891	+0.5	20	None	6	6	Spongy
14	C	Not weighed	. . .	22	None	6	6	Spongy, flakes lost
15	C	0.4885	—0.1	22	None	6	6	Good

Table No. III shows the results obtained without rotation. It is evident that at least 8 to 10 drops of nitric acid are necessary to obtain a satisfactory deposit, and that even with this amount of acid the precipitate was likely to be dark and spongy, from no apparent cause. In Table II, determinations 7-11 show that with a cold electrolyte no satisfactory results could be obtained with this method. The use of the larger amounts of nitric acid recommended by the Messrs. Palmer gave us in one trial complete precipitation in the time indicated by them, and the precipitate was of satisfactory character. On other trials, however, the precipitate at first formed re-dissolved, as described by Withrow,[7] and would not re-precipitate on further electrolysis for several hours. The amount of acid used is evidently far in excess of that necessary, and the excess has a decidedly bad effect on the analysis.

[7] J. Am. Chem. Soc., **30**, 381 (1908).

Table IV.

Precipitation on gauze cathode without rotation, from HNO_3 electrolyte. Current, 8 amperes, except Nos. 3 (7.5 amp.) and 7 (8.2 amp.). Volts, 10-12. Temperature at start, 60° to 70°. Concentrated acids added.

No.	Sol.	Wt. Found Gm.	Error Mg.	Time Min.	Copper Left	Acid (Drops)		Character of Deposit
						HNO_3	H_2SO_4	
1	C	0.4884	—0.2	8	Trace	7	0	Bulky, loose
2	C	0.4852	—3.4	8	Much	7	0	Bulky
3	C	Not weighed	. . .	10	None	6	0	Spongy, portions fell off
4	C	0.4882	—0.4	10	None	7	0	Spongy, non-adherent
5	B	0.5485	+2.9	10	None	5	8	Spongy, voluminous
6	C	Not weighed	. . .	12	None	7	0	Same as No. 3
7	B	Not weighed	. . .	13	None	10	8	Same as No. 3

Table No. IV shows an attempt to reproduce the results of Stoddard. It is readily seen that the criticism of his results made by one of us in the discussion of the paper of the Messrs. Palmer[8] was justified in all particulars. The deposition was not complete in the shorter time mentioned by him (8 minutes), and the deposit was of such a poor character as to make the method entirely unreliable. In three of the determinations portions of the precipitate were observed to have fallen off, and it is probable that loss occurred in No. 4 also.

For purposes of comparison, a number of determinations were made with a dish cathode and a rotating spiral anode according to Smith. Complete and satisfactory deposition was obtained in 11 to 12 minutes, as stated by him.

Using about 1.1 gm. copper, complete and satisfactory precipitation was obtained in about 40 to 45 minutes with magnetic rotation of the solution, while with no rotation 10 to 15 minutes longer were required. In the latter case the precipitate showed a decided tendency toward sponginess and excess weight.

Using smaller quantities of copper (0.05 to 0.1 gm.), 8 to 10 drops of nitric acid appeared to be necessary, and the deposits without rotation were better than when larger quantities of copper were used. Deposits from the rotating solution were of rather better appearance than those made without rotation, and deposi-

[8] Trans. Am. Electrochem. Soc., **15**, 495 (1909).

tion was obtained in 8 to 10 minutes, as compared with 12 to 14 minutes in the latter method.

From these determinations, more than 150 in all, we conclude that, in the case of copper, precipitation by the rotating anode is complete and satisfactory in a few minutes less than with magnetic rotation. Precipitation with magnetic rotation is complete and satisfactory in a little shorter time than when no rotation is used. In the last case, however, the character of the precipitate is much more variable, and often for no apparent reason the deposit becomes unweighable. Possibly with the use of somewhat more nitric acid the character of this deposit might have been improved, but the time required would naturally have been longer and the certainty of complete precipitation much less. In all cases the solution should be heated to 70° before electrolysis, the heat evolved by the current maintaining this temperature during the process.

It is to be noted, however, that the comparatively favorable results obtained in the deposition of copper on the gauze cathode alone do not show that stirring or rotation of the solution may be generally dispensed with. Copper is well known to be one of the easiest metals to deposit under widely varying conditions, and it remains to be seen what results can be obtained with other metals.

Electrochemical Laboratory,
University of Minnesota,
April 5, 1910.

DISCUSSION.

MR. J. S. GOLDBAUM: Professor Stoddard has suggested the use of platinum gauze anodes and cathodes, and Price and Humphries have continued the work of Stoddard; they have found that the gauze electrode is not as good as the rotating electrode. Dr. Frary now comes to the same conclusion. In the University of Pennsylvania we have made a number of determinations with both Stoddard's and Frary's methods; we find that with Stoddard's method satisfactory deposits are obtained

with copper, zinc, nickel and cobalt, but those of tin, antimony, iron, bismuth and molybdenum are very bad, and with the latter rotating electrodes are absolutely necessary. None of these results have so far been published.

Dr. Frary says that ammonium potassium cyanide with 10 per-cent ammonia, prevents the solution of the platinum and deposition of it on the cathode. We tested this same solution at the University of Pennsylvania, and found that its use was a positive preventative of the solution of the platinum, pure copper only being deposited.

Dr. Frary says that silver deposited from potassium cyanide solutions contains cyanogen; this statement is true. It often contains some cyanogen after ignition. This can be avoided by dipping the electrode into hydrochloric acid a moment and washing followed by ignition. It will then be found to consist of pure silver.

When silver is deposited from an ammonical potassium cyanide solution in a platinum dish, the silver can be dissolved away from the dish leaving the latter clean, but if the silver is first ignited and then boiled in nitric acid a black scum will be left on the platinum which is insoluble in acids and alkalies but burns off on ignition and acts like carbon. I have not been able to determine exactly what it is.

Mr. J. S. Withrow: I have observed the same phenomenon of the black scum on the platinum, and I have also been unable to determine what causes it.

A paper presented at the Seventeenth General Meeting of the American Electrochemical Society, at Pittsburgh, Pa., May 7, 1910, President L. H. Baekeland in the Chair.

A ROTATING GRAPHITE ANODE.

By J. W. Turrentine.

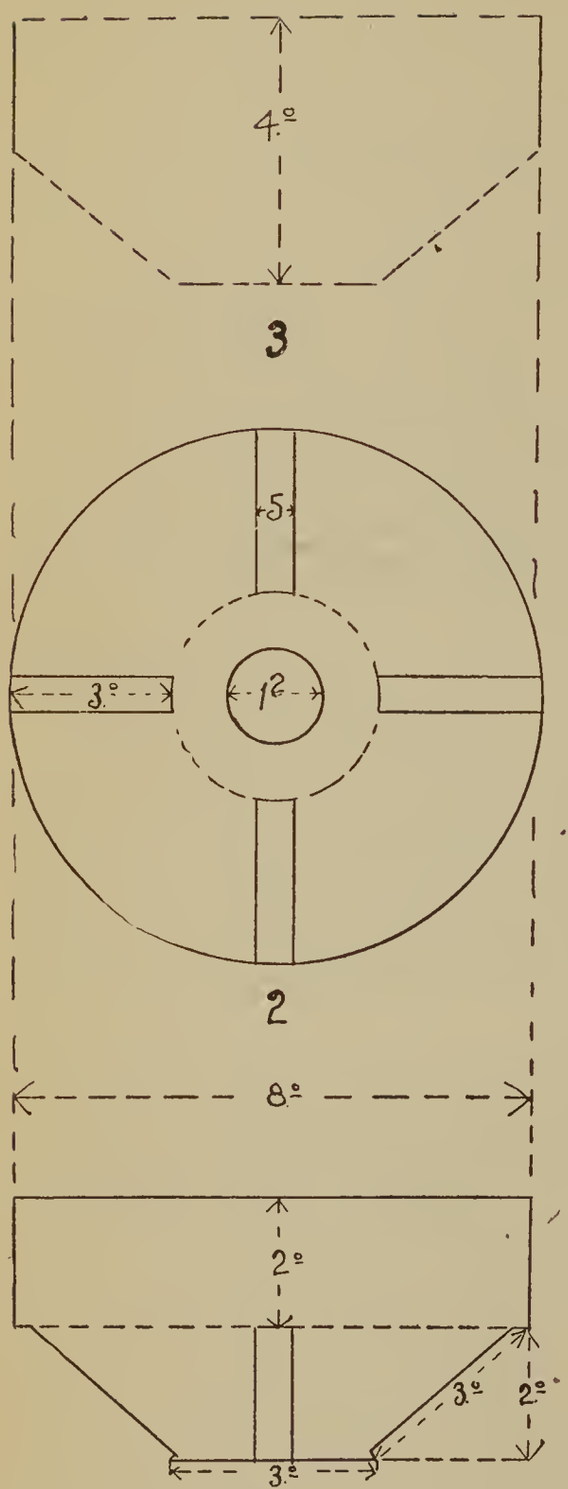
Mention has already been made of designs of a rotating graphite anode which was to accompany the graphite cathode dish.[1] This piece of apparatus has now been made and is in use. Its serviceableness when employed in connection with the platinum Classen dish, as well as with the graphite cathode dish, is such that, although the anode is not yet perfected, this preliminary account of it is deemed warranted.

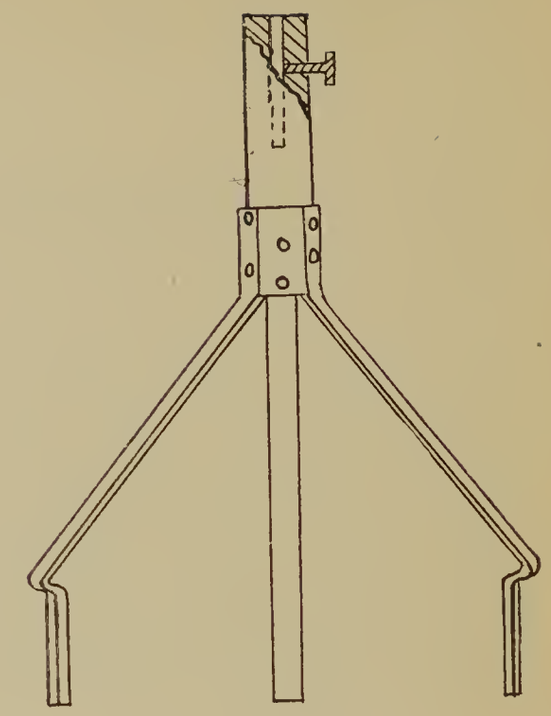
The graphite anode, it is hoped, may be found capable of supplanting the vastly more expensive platinum anode in electrochemical analysis and other electrochemical processes where the rotating anode is used. As has been pointed out,[1] many of the beautiful and time-saving methods of electro-analysis and of electrochemical operations might fail of adoption because of the expense of the platinum apparatus involved. When graphite is employed, the expense is minimized.

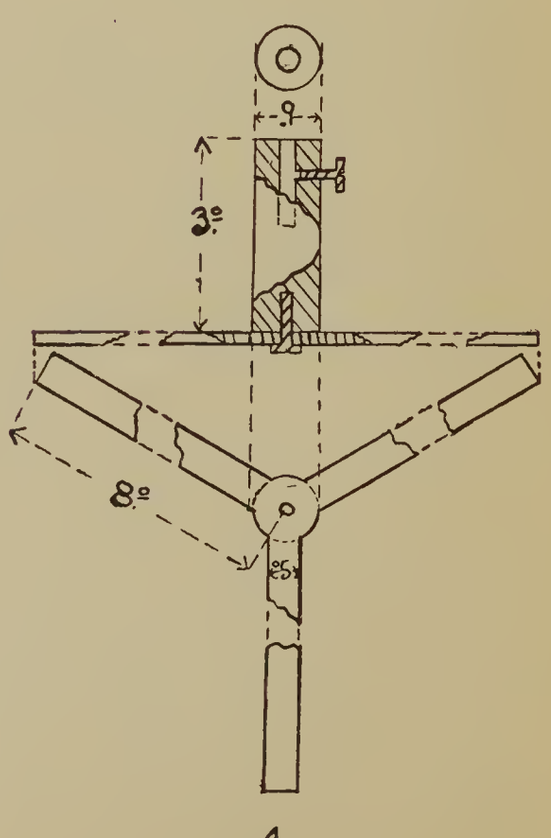
Little attention has been paid heretofore to special forms of anodes in electro-analysis. The efforts of the developers of this branch of electrochemistry have been directed rather towards perfecting the cathode. There are therefore, several useful forms of cathodes which possess both of the desired qualities of lightness in weight and of large surface area. There is still, however, need of a cheap form of rotating anode which is constructed of some non-corrodible material and which presents a large surface area. The electrical resistance within the cell then may be so slight that currents of considerable strength may be passed without difficulty.

The chief advantage to be gained from rotating the anode instead of the cathode is that the anode is then placed above the cathode, instead of in the reverse order; the oxygen which is evolved from the former does not bubble over the surface of

[1] Turrentine, Jr. Phys. Chem., **13**, 438 (1909); Trans. Amer. Electrochem. Soc., **15**, 505 (1909); Chem. Abstr., **4**, 691 (1910).







FIGS. 1, 2, 3, 4, 5.

the latter and there oxidize the deposited metal. On the other hand, the stirring in the cathode region is not so effective when the anode is rotated as when the cathode is rotated. However, when the two poles are as close to each other as they are in the apparatus which is to be described in this paper, there can be but a very slight difference in the relative effectiveness of the stirring in the electrode regions.

By means of a rotating dish anode and a dish cathode, both of platinum and the two of the same general shape, Miss Langness[2] performed electro-analyses with current strengths as great as 16 amperes on the laboratory cell. A half gram of copper was precipitated with this apparatus in six minutes, and an equal amount of silver in two minutes. The results obtained showed a very good agreement with the theoretical values, and the time consumed was unprecedently short.

The anode used was fashioned from a platinum dish by cutting ten radial slits in its sides and by soldering, or otherwise fastening, across its top a stout platinum wire, to the center of which was attached, T-wise, a perpendicular platinum rod to serve as the axis. This apparatus, being constructed of platinum, is expensive.

The anode which it is the purpose of this paper to describe is constructed of an especially hard grade of Acheson graphite. It is dish-shaped. It is cut from stick graphite, and is turned down on a lathe to the desired size and thickness.

The anode in use was designed to accompany the graphite cathode dish, and is constructed so as to conform in shape to the shape of that dish. Its diameter is 8 cm. and its depth is 4 cm. For a depth of 2 cm. from the top the object is cylindrical. (See Figs. 1, 2 and 3.) The contour below the cylindrical portion is that of a truncated cone. The truncation serves as the base. The slope of the frustum reduces the diameter from 8 cm. at the bottom of the cylindrical portion to 3 cm. at the truncation. The lateral dimension of the cone is also 3 cm. In the walls of the conical portion are cut four radial equidistant slits. These extend from the lower edge of the cylindrical part to the edge of the base. In the base is also an opening, centrally placed, which is circular in shape and is 1.2 cm. in diameter.

[2] Jr. Amer. Chem. Soc., **29**, 459 (1907).

The orifices permit the solution contained in the cell to flow into the interor of the electrode. However, when the anode is being rotated, the centrifugal force generated holds nearly all of the solution in the space outside the anode. When the cathode is also dish-shaped this space may be quite narrow. Then, while the electrode rotates, practically the entire volume of the solution is held constantly within the zone of activity between the two electrodes. The arrangement of the openings is also such that the effect of a Witt stirrer is produced. The solution is drawn into the interior of the anode through the lower, axially-placed opening in the bottom of the anode, where the centrifugal force is low, and is thrown out through the lateral slits, where the centrifugal force is high. Gravitational forces then bring the solution back to the bottom of the cell.

From these statements it may be inferred that the active surface of the electrode is the outside surface. This is practically true, though it has been noted, when the electrode has been used as a cathode for the deposition of metal, that some metal is deposited on the interior, in regions near the edges of the orifices.

The dish-like contour of the anode is of especial advantage when the anode is used in connection with a cathode dish. The two poles may then be brought quite close together along their entire surfaces. The distance through the solution traversed by the current is then very short, and the resistance is correspondingly low. The diameter of the anode is 8 cm. The diameter of the graphite cathode dish designed to be accompanied by the anode is 9.5 cm. The space between anode and cathode then may be as short as 0.75 cm.

The truncated conical shape of anode was planned with the thought in mind that perhaps an object with straight edges might be more easily cut than one whose periphery was a spherical section. Drawings of both the spherical and the truncated conical shape were given the manufacturers.[3] The one described has been chosen by them. A possible slight advantage of the hemispherical form is that a somewhat larger surface area is afforded per unit of weight of graphite, presupposing walls of equal thickness. The graphite anode which has been in use in this labora-

[3] Messrs. Eimer & Amend, New York.

tory has walls of 1 mm. in thickness, the same as those of the cathode dishes. Such a degree of thinness is undesirable on account of the lack of durability of the article. Nor is the thinness of the walls and the resulting lightness so important in the case of the anode as in that of the cathode, as the former rarely has to be weighed. The heavier the anode, however, the greater the weight will be on the bearings of the rotator and the more power will be required consequently to operate it. The best results could be obtained probably with walls of 2-3 mm. in thickness. Such a thickness is recommended.

The surface area of the anode is, roughly, 80 sq. cm. Such a large electrode surface decreases the resistance in the cell.[4]

A very satisfactory form of support for the anode, made of aluminum, is now in use. To a solid aluminum cylinder, which serves as the axis, are fastened three aluminum prongs, equidistant apart. The axial cylinder is 4 cm. long and for 2.8 cm. of its length is 0.9 cm. in diameter; for the remaining distance it is 1.2 cm. in diameter. It is provided with a hole in its top, inserted axially, to accommodate the axis of an electric motor or other rotating device. A screw enters this opening at right angles, by means of which the connection with the motor may be made secure. To the lower, enlarged portion of the cylinder are fastened the three prongs by means of rivets. The prongs are 8 cm. long, 0.5 cm. wide, and 0.2 cm. in thickness. They extend downward and outward from the axis; the circumference of the circle described by their points when the support is rotated is somewhat larger than that of the anode. When these are pressed inward, the anode may be slipped over them. Then, on being released, they press outward against the inner walls of the anode with sufficient force to hold it in position. Fig. 5 was drawn from this support.

A support of practically the same plan and of equal efficiency could be made by cutting the prongs in one piece from sheet aluminum and fastening this piece by means of a screw to the bottom of the cylindrical piece. The prongs could then be bent to the desired angle and shape. This method of manufacture is illustrated in Fig. 4.

The cylindrical piece is 3 cm. in length. The prongs should

[4] Turrentine, "The Meaning of Current Density," Jr. Phys. Chem., **14**, 152 (1910).

be cut as represented, each being about 8 cm. in length from their common center. Through this center passes the screw which fastens the prongs to the axis. The finished support would have very much the same appearance as that shown in Fig. 5.

The aluminum support so far has been found entirely satisfactory. It is not necessary that the ends of the prongs should come into contact with the solution at all, this depending on the depth of the solution inside the anode. Yet, when they do, the corrosion is extremely slight, as aluminum becomes passive in solutions of most electrolytes. Nor would the presence of small amounts of aluminum in the solution undergoing electrolysis prove disadvantageous. The oxidation of the aluminum does not become sufficient to interfere with the electrical contact between the aluminum and the graphite. Should the solubility of the aluminum make its use prove undesirable, other metals could be substituted in part or in whole. The tips of the prongs could be covered with platinum foil without very materially increasing the expensiveness of the apparatus.

As suggested, the rotation is effected by fastening the support directly to the shaft of a small electric motor of the "Ajax" type. This is the simplest and is perhaps the cheapest arrangement. Current may be admitted to the motor from a 110-volt circuit through incandescent lamps as resistance. By means of lamps of low candle power, the current, and, therefore, the speed of the motor, may be regulated satisfactorily. Electrical connection is made with the anode through the metal bearings of the motor, or by means of a brush playing on the aluminum support. The insulation in such cheap motors is often so poor that leakage currents from the circuit operating the motor may find their way through the solution undergoing electrolysis. This tendency may be controlled or entirely overcome by a suitable arrangement of the electrical connections and the resistance controlling the electrolyzing current.

The rotating apparatus here described affords a perfectly smooth agitation of the solution and causes no spattering; only that arising from the liberation of a large volume of gas is noticed.

The qualities possessed by graphite which make it a desirable substance of which to construct an anode are its absolute insolu-

bility, its cheapness and its high conductivity. Platinum is usually accepted as the more nearly ideal metal for use as a non-attackable anode. However, it can no longer be regarded as an insoluble metal, although for most electrolyses, where its behaviour is known beforehand, it is entirely satisfactory. Anodes of other metals plated with platinum would be both expensive and quite untrustworthy.

The objections to graphite so far discovered are its porosity and its tendency to flake off at high current densities.

While porosity would be quite non-permissible in a cathode, it need not be such an objection in an anode. This is especially true where the anode is being used exclusively in solutions of the same character. Under these conditions no impurities would be introduced by absorbed materials entering the solution from the anode. However, the porosity of the graphite has been practically entirely overcome by the treatment with paraffin or ceresine already described.[5]

The disintegration of the graphite at the anode is noticed only at high current densities. This would be objectionable because it would mean the eventual destruction of the anode. Likewise it is concievable that in quantitative electro-analyses of metals, particles of graphite would be occluded by the depositing metal and the weight of the latter thereby increased. Yet this phenomenon is noticed only at high current densities; and the large surface area of the graphite anode makes possible the use of large current strengths without at the same time producing high current densities.

The problem, how to prevent the "flaking off" of the graphite, is now being investigated in this laboratory. Electrodes treated in various ways to render them more resistant are being compared with each other under like conditions in solutions of various electrolytes and at various current densities. The results so far obtained would indicate that no disintegration occurs with a paraffined graphite anode under a current density of 6 amperes per square decimeter. With the anode described, then, a current of at least 5 amperes may be employed with impunity.

It has been thought by some that paraffining graphite would decrease its conductivity. While probably no accurate measure-

[5] "A Graphite Cathode Dish," *loc. cit.*

ments have been made to determine the effects of paraffining on the conductivity, that property of the graphite is not conspicuously impaired. It appears that the resistance of the solution and that due to polarization phenomena are so great in comparison with that produced by the presence of the paraffin that the latter resistance is entirely negligible.

The anode as described has been employed with success in numerous electrochemical processes, in electrochemical analyses and separations of metals and in electrochemical oxidations. It has been employed also as a rotating cathode. In its present state of development it has shown itself a useful piece of apparatus. After further experimentation it is hoped that its present defects may be overcome so that it may be given an unqualified recommendation.

Wesleyan University,
April, 1910.

A paper presented at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 7, 1910, President L. H. Baekeland in the Chair.

THE TOWNSEND CELL: ITS BEHAVIOR UNDER VARIOUS CURRENT DENSITIES

By H. K. Richardson and R. L. Patterson.

The work embodied in this paper was carried out to obtain data by which to operate a Townsend Cell for laboratory work.

Description of Cell.

The cell was built in the laboratory, and was our interpretation of the description given in the June, 1907, number of the Electrochemical and Metallurgical Industry. Fig. 1 gives the detail construction of the cell. Figs. 2, 3, 4 give photographs of the cell as it was connected in the circuit. The diaphragms used were furnished by Mr. A. H. Hooker, of the Hooker Electrochemical Co., Niagara Falls, New York. In use these were backed by one sheet of asbestos paper.

A few of the most important points of the cell are as follows:

Cathode surface area, 4 square feet (36 sq. dm.) active surface.

Anode surface area, 1 square foot active surface.

Ratio[1]—anode to cathode surface, 1 : 4.

Distance[2]—anode to cathode, 2⅛ inches (5.3 cm.).

The cathode plate was perforated by punching a ¼-in. (0.62 cm.) hole at the corner of each square inch.

Method of Conducting Test.

Current was supplied from a 5-kw. low-voltage generator, which accounts somewhat for the current variation. Regulation was by means of the field rheostat of the machine. In every run the cell was allowed to arrive at approximately constant con-

[1] Commercial Practice ratio is 1 : 1½.

[2] Commercial Practice distance is ⅜"—½".

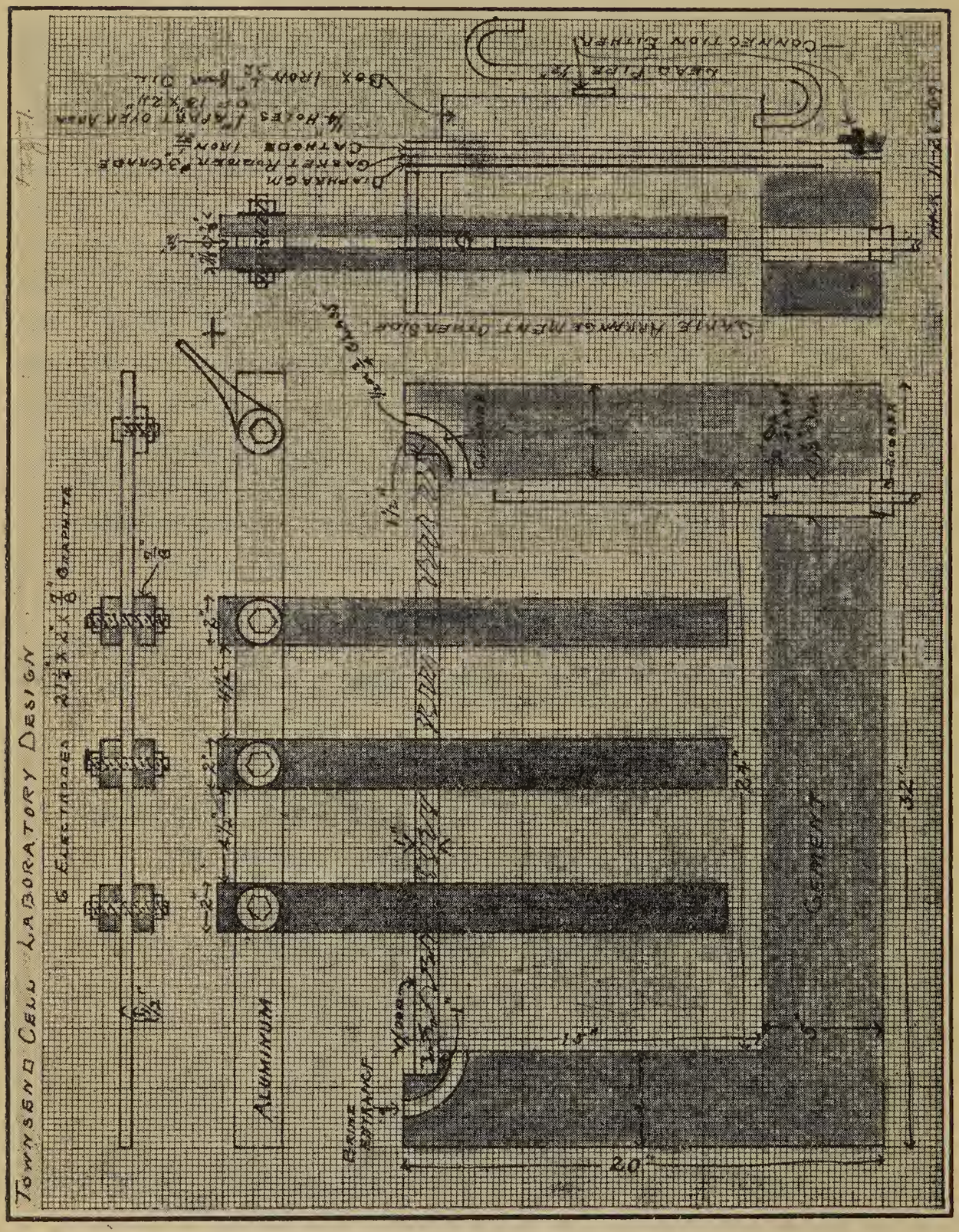

TOWNSEND CELL LABORATORY DESIGN
6 ELECTRODES 2½" x 2½" x ⅝" GRAPHITE
ALUMINIUM
CEMENT
20"
32"
15"
24"

FIG. 1.

ditions of voltage and current before readings were taken. No variations in the setting of either goose-neck or over-flow tube were made during test. The oil level in the outside chamber was about 1 in. below the brine level. The caustic liquor was caught only during the one hour of the run. Its NaOH content was obtained by titration with HCl and phenolpthalein. The chlorine was sucked away to the sewer.

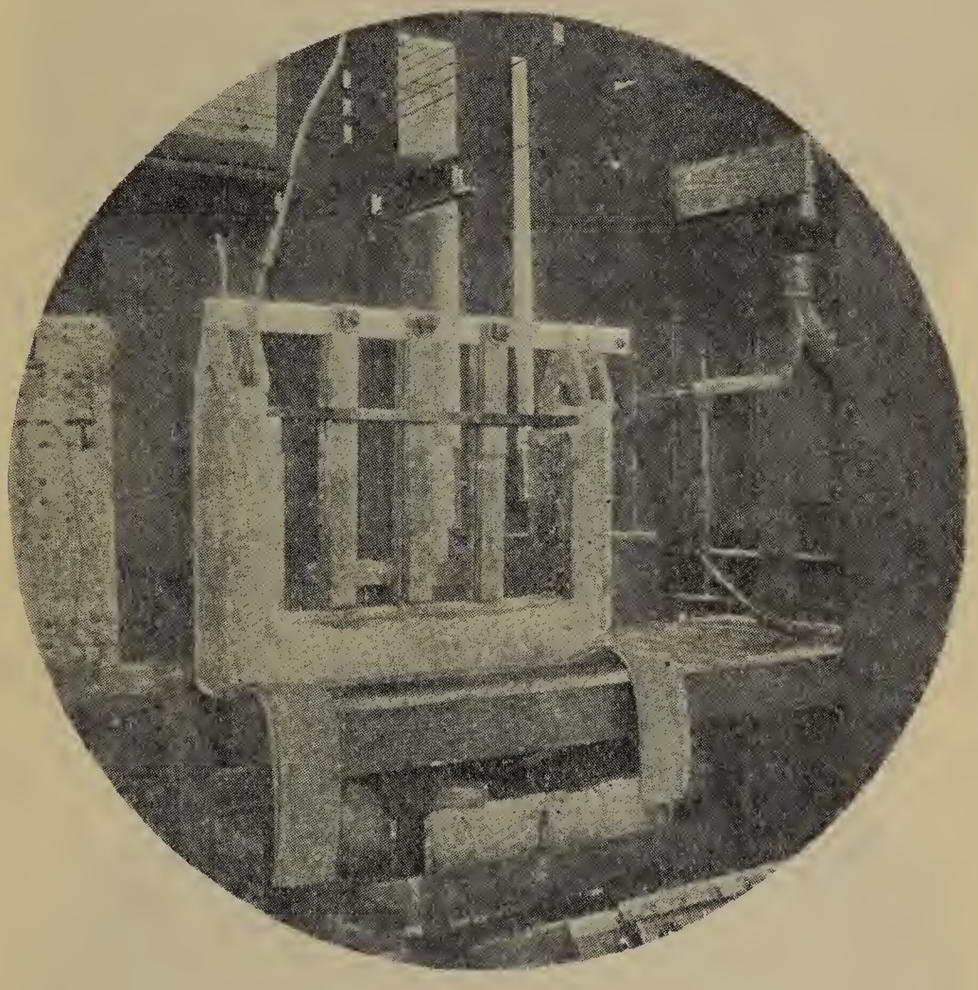


FIG. 2.

The brine used in all of the experiments was of 1.17-1.18 specific gravity at about 20° C.

The experiments are divided into three series, in each of which the anode flow was constant, while the current density was the variable.

Data.

Below are tabulated the results of the separate runs. Five-minute readings were taken, but only 10-minute readings are given. The averages, however, are for 13 readings.

FIG. 3.

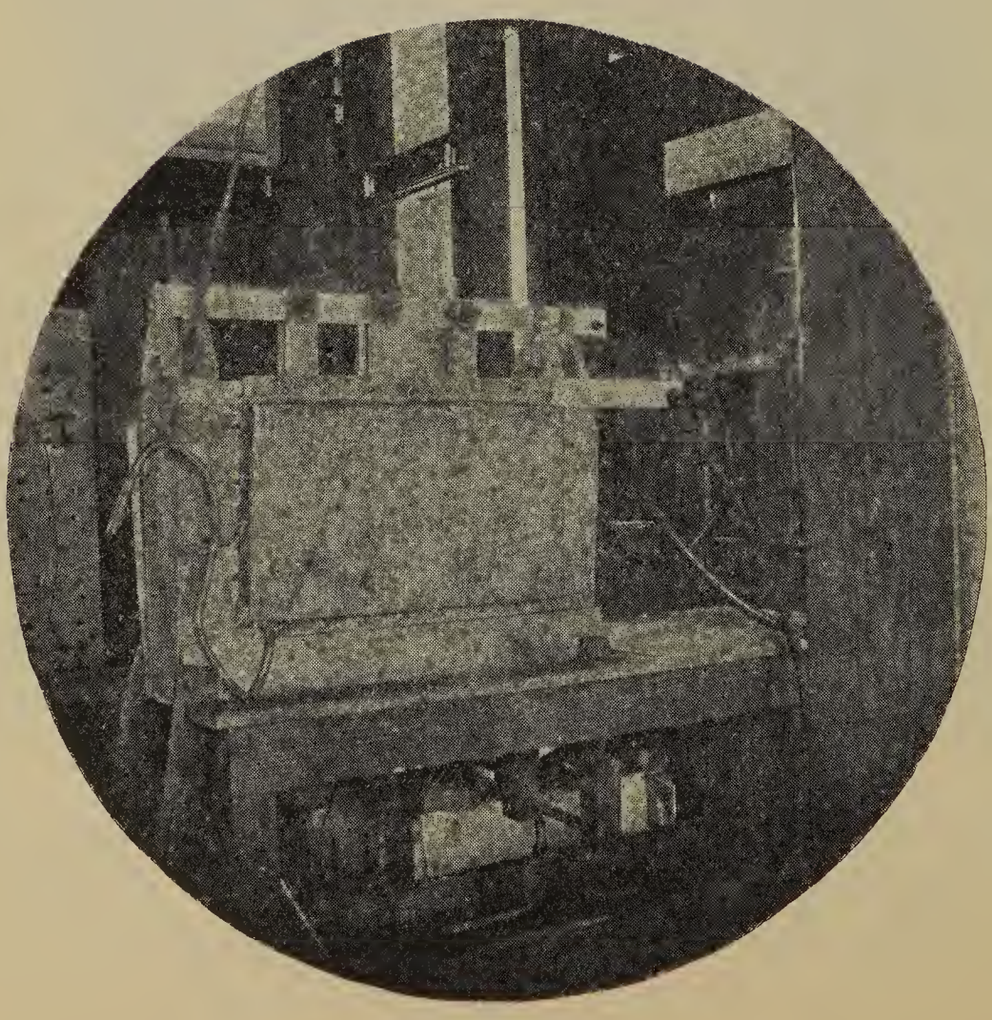


FIG. 4.

Series I: Rate of Anode Flow = 1500 c.c. per hour.
25 " " minute.

TABLE 1.

Current Density { Cathode = 4.52 amperes / sq. ft. (0.5 A. per sq. dm.)
Anode = 18.1 " " (2 A. " ")

Time.	Amperes.	Volts Across Cell.	Temp. °C.
0 Min.	19	3.21	21.0
10 "	18	3.20	
20 "	16	3.20	
30 "	18	3.23	21.5
40 "	18	3.20	
50 "	18	3.22	
60 "	18	3.22	22.2
	Av. 18.08	Av. 3.22	1.2 Rise

Total ampere hours	=	18.1
Voltage loss in contacts	=	0.11
Corrected volts across cell	=	3.11
Total kilowatt hours	=	0.056
Cathode effluent, side A	=	4.100 litres
" " " B	=	6.100 "
" " total	=	10.200 "
Strength of caustic	=	0.26 grams per 100 c.c.
Total yield of caustic	=	26.5 "

TABLE 2.

Current Density { Cathode = 19.7 amperes / sq. ft. (2.2 A. per sq. dm.)
Anode = 78.7 " " (8.7 A. " ")

Time.	Amperes.	Volts Across Cell.	Temp. °C.
0 Min.	76.0	4.45	21.0
10 "	77.0	4.50	
20 "	76.0	4.45	
30 "	76.0	4.40	
40 "	81.0	4.50	
50 "	82.0	4.52	
60 "	82.0	4.52	22.8
	Av. 78.7	Av. 4.47	1.8 Rise

Total ampere hours	=	78.7
Voltage loss in contacts	=	0.25
Corrected volts across cell	=	4.22
Total kilowatt hours	=	0.332
Cathode effluent, side A	=	3.600 litres
" " " B	=	5.800 "
" " total	=	9.400 "
Strength of caustic	=	1.11 grams per 100 c.c.
Total yield of caustic	=	104. "

Table 3.

Current Density { Cathode = 40.0 amperes / sq. ft. (4.4 A. per sq. dm.)
Anode = 160. " " (18 A. " ")

Time.	Amperes.	Volts Across Cell.	Temp. °C.
0 Min.	158	5.55	27.0
10 "	173	5.70	
20 "	148	5.15	
30 "	158	5.11	
40 "	158	5.15	
50 "	158	5.15	
60 "	159	5.15	29.5
	Av. 159.5	Av. 5.27	2.5 Rise

Total ampere hours	=	159.5
Voltage loss in contacts	=	0.40
Corrected volts across cell	=	4.87
Total kilowatt hours	=	0.776
Cathode effluent, side A	=	2.500 litres
" " " B	=	5.200 "
" " total	=	7.700 "
Strength of caustic	=	2.62 grams per 100 c.c.
Total yield of caustic	=	201. "

Table 4.

Current Density Cathode = 62.8 amperes / sq. ft. (7 A. per sq. dm.)
Anode = 251. " " (28 A. " ")

Time.	Amperes.	Volts Across Cell.	Temp. °C.
0 Min.	250	6.80	47.0
10 "	250	6.70	
20 "	257	6.65	
30 "	248	6.42	48.2
40 "	258	6.65	
50 "	251	6.60	
60 "	248	6.20	50.0
	Av. 251	Av. 6.56	3.0 Rise

Total ampere hours	=	251.
Voltage loss in contacts	=	0.72
Corrected volts across cell	=	5.84
Total kilowatt hours	=	1.46
Cathode effluent, side A	=	3.560 litres
" " " B	=	3.860 "
" " total	=	7.420 "
Strength of caustic	=	4.00 grams per 100 c.c.
Total yield of caustic	=	297. "

TABLE 5.

Current Density { Cathode = 123 amperes / sq. ft. (14 A. per sq. dm.)
Anode = 492 " " (55 A. " ")

Time.	Amperes.	Volts Across Cell.	Temp. °C.
0 Min.	493	8.30	69.6
10 "	498	7.60	
20 "	496	7.35	
30 "	492	7.40	
40 "	492	7.55	
50 "	488	7.70	
60 "	488	7.70	76.0
	Av. 492	Av. 7.65	6.4 Rise

Total ampere hours = 492.
Voltage loss in contacts = 1.2
Corrected volts across cell = 6.45
Total kilowatt hours = 3.17
Cathode effluent, side A = 3.500 litres
" " " B = 3.960 "
" " total = 7.460 "
Strength of caustic = 7.82 grams per 100 c.c.
Total yield of caustic = 582. "

Series II: Rate of Anode Flow = 12,000 c.c. per hour.
200 " " minute.

TABLE 6.

Current Density { Cathode = 4.43 amperes / sq. ft. (0.5 A. per sq. dm.)
Anode = 17.7 " " (2 A. " ")

Time.	Amperes.	Volts Across Cell.	Temp. °C.
0 Min.	18.0	3.15	20.2
10 "	19.0	3.20	
20 "	17.0	3.15	
30 "	18.0	3.15	20.4
40 "	16.0	3.05	
50 "	18.0	3.17	
60 "	17.0	3.10	20.8
	Av. 17.7	Av. 3.14	0.6 Rise

Total ampere hours = 17.7
Voltage loss across contacts = 0.09
Corrected volts across cell = 3.05
Total kilowatt hours = 0.54
Cathode effluent, side A = 6.000 litres
" " " B = 8.200 "
" " total = 14.200 "
Strength of caustic = 0.18 grams per 100 c.c.
Total yield of caustic = 25.6 "

Table 7.

Current Density { Cathode = 62.3 amperes / sq. ft. (7 A. per sq. dm.)
Anode = 249. " " (28 A. " ")

Time.	Amperes.	Volts Across Cell.	Temp. °C.
0 Min.	247	6.85	39.0
10 "	249	6.80	
20 "	243	6.60	
30 "	253	6.60	
40 "	250	6.60	
50 "	251	6.60	
60 "	252	6.60	41.8
	Av. 249.4	Av. 6.67	2.8 Rise

Total ampere hours = 249.
Voltage loss in contacts = 0.70
Corrected voltage across cell = 5.97
Total kilowatt hours = 1.49
Cathode effluent, side A = 5.600 litres
" " " B = 8.600 "
" " total = 14.200 "

Strength of caustic = 2.1 grams per 100 c.c.
Total yield of caustic = 298.0 "

Table 8.

Current Density { Cathode = 124 amperes / sq. ft. (14 A. per sq. dm.)
Anode = 497 " " (55 A. " ")

Time.	Amperes.	Volts Across Cell.	Temp. °C.
0 Min.	498	8.80	52.0
10 "	498	8.55	
20 "	503	8.40	
30 "	498	8.25	
40 "	506	8.05	
50 "	498	8.00	
60 "	501	7.95	58.0
	Av. 497.2	Av. 8.25	6.0 Rise

Total ampere hours = 497.
Voltage loss in contacts = 1.10
Corrected volts across cell = 7.15
Total kilowatt hours = 3.55
Cathode effluent, side A = 5.400 litres
" " " B = 8.400 "
" " total = 13.800 "

Strength of caustic = 4.38 grams per 100 c.c.
Total yield of caustic = 594.0 "

Series III: Rate of Anode Flow = 36,000 c.c. per hour.
600 " " minute.

TABLE 9.

Current Density { Cathode = 5.00 amperes / sq. ft. (0.55 A. per sq. dm.)
Anode = 20.0 " " (2.2 A. " ")

Time.	Amperes.	Volts Across Cell.	Temp. °C.
0 Min.	20.0	3.08	19.0
10 "	19.0	3.06	
20 "	20.0	3.10	
30 "	21.0	3.10	
40 "	20.0	3.08	
50 "	21.0	3.00	
60 "	20.0	3.10	19.1
	Av. 20.0	Av. 3.08	0.1 Rise

Total ampere hours = 20.0
Voltage loss across contacts = 0.10
Corrected voltage across cell = 2.98
Total kilowatt hours = 0.0596
Cathode effluent, side A = 4.700 litres
" " " B = 5.800 "
" " total = 10.500 "

Strength of caustic = 0.26 grams per 100 c.c.
Total yield of caustic = 27.3 "

TABLE 10.

Current Density { Cathode = 61.8 amperes / sq. ft. (6.9 A. per sq. dm.)
Anode = 246. " " (27 A. " ")

Time.	Amperes.	Volts Across Cell.	Temp. °C.
0 Min.	247	6.25	43.0
10 "	233	6.30	
20 "	259	6.75	
30 "	243	6.50	
40 "	246	6.50	
50 "	246	6.50	
60 "	245	6.48	45.4
	Av. 245.5	Av. 6.49	2.4 Rise

Total ampere hours = 246.
Voltage loss in contacts = 0.70
Corrected voltage across cell = 5.79
Total kilowatt hours = 1.42
Cathode effluent, side A = 5.600 litres
" " " B = 7.400 "
" " total = 13.000 "

Strength of caustic = 2.26 grams per 100 c.c.
Total yield of caustic = 294.0 "

Table II.

Current Density { Cathode = 125. amperes / sq. ft. (14 A. per sq. dm.)
Anode = 500. " " (55 A. " ")

Time.	Amperes.	Volts Across Cell.	Temp. °C.
0 Min.	498	8.00	60.0
10 "	493	8.00	
20 "	503	8.10	
30 "	500	8.00	
40 "	498	8.00	
50 "	499	8.00	
60 "	498	8.10	65.0
	Av. 500	Av. 8.03	5.0 Rise

Total ampere hours = 500.
Voltage loss in contacts = 1.03
Corrected voltage across cell = 7.00
Total kilowatt hours = 3.50
Cathode effluent, side A = 4.600 litres
" " " B = 5.600 "
" " total = 10.200 "

Strength of caustic = 6.24 grams per 100 c.c.
Total yield of caustic = 649.0 "

TABLE 12.

Summary of Results (Data).

Rates of Anode Flow $\left\{\frac{\text{c.c.}}{\text{Minute}}\right.$ $\left.\frac{\text{c.c.}}{\text{Hour}}\right\}$	25					200			600		
	1500					12000			36000		
Current Density $\left(\frac{\text{Amp.}}{\text{Sq. Ft.}}\right)$ Anode .	18.1	78.7	160.0	251	492	17.7	249	497	20.0	247	500
Current Density $\left(\frac{\text{Amp.}}{\text{Sq. Ft.}}\right)$ Cathode	4.52	19.7	40.0	62.8	123	4.43	62.3	124	5.00	61.8	125
Current Density $\left(\frac{\text{Amp.}}{\text{Sq. Dm.}}\right)$ Anode	2.0	8.7	17.8	28.0	54.7	2.0	27.7	55.2	2.2	25.2	55.5
Current Density $\left(\frac{\text{Amp.}}{\text{Sq. Dm.}}\right)$ Cathode	0.5	2.2	4.4	7.0	13.7	0.5	6.9	13.8	0.6	6.9	13.9
Current Efficiency, percent	98.3	91.4	84.8	79.5	79.3	86.9	80.0	81.8	91.6	80.4	84.8
Energy Efficiency, percent .	72.6	49.8	40.0	31.3	28.3	73.0	30.6	26.0	74.1	31.9	27.8
Total Yield of NaOH, Grams	26.5	104	201	297	582	25.6	298	594	27.3	294	649
Grams NaOH per 100 c.c. .	0.26	1.11	2.62	4.00	7.80	0.18	2.10	4.30	0.26	2.26	6.36
Grams NaOH per K.W. Hour	473	314	259	235	184	472	200	170	462	207	180
Voltage, Average	3.11	4.20	4.87	5.84	6.45	3.05	5.97	7.15	2.98	5.79	7.00
Amperage, Average	18.1	80.2	160	251	492	17.7	249	499	20.0	246	500
Kilowatt Hours	0.056	0.332	0.776	1.46	3.17	0.054	1.49	3.56	0.059	1.42	3.50
Total Cathode Flow $\frac{\text{1000 c.c.}}{\text{Hour}}$	10.2	9.40	7.70	7.42	7.46	14.2	14.2	13.8	10.5	13.0	10.2
Temperature, 1 Hour Rise °C	1.2	1.8	2.5	3.0	10.0	0.6	2.8	6.0	0.1	2.4	5.0

SUMMARY OF RESULTS.

Efficiencies.

(1) Current efficiency decreases with increasing current density, till value of 80% is reached at current density of 250 amperes per sq. ft. (28 A. per sq. dm.), after which it remains constant. Fig. 5.

(2) Energy efficiency decreases rapidly with increasing current

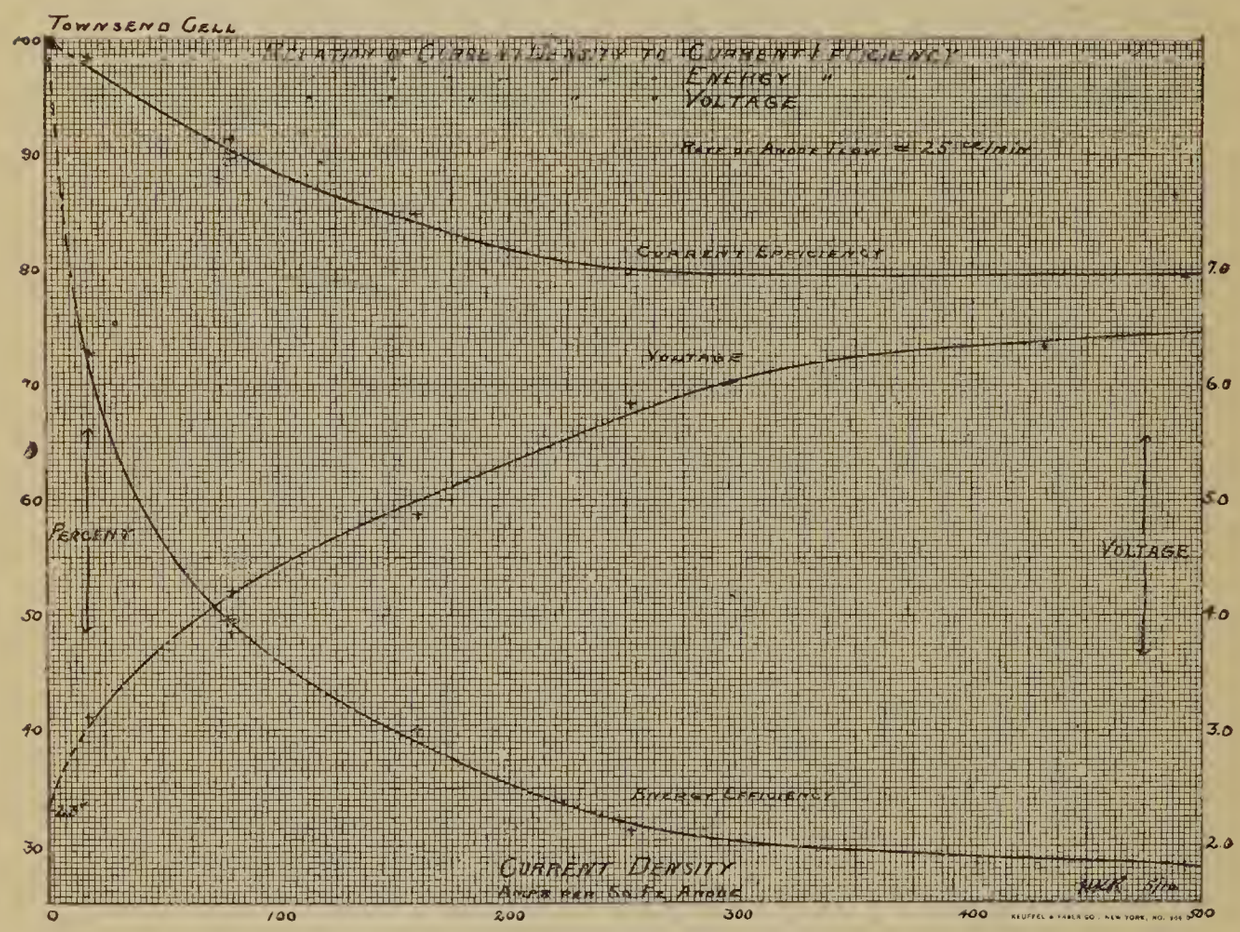


FIG. 5.

density, until value of 30% is reached at 250 amperes per sq. ft. (28 A. per sq. dm.), after which it decreases at a much slower rate. Fig. 5.

(3) Both current and energy efficiencies appear to be little affected by varying rates of anode flow. Table 12.

Voltage.

(4) Voltage rises from 3.1 to 6.5, as current density increases from 20-250 amperes per sq. ft. (2.2 to 28 A. per sq. dm.). Fig. 5.

(5) Voltage is little affected by varying rate of anode flow. Table 12.

Strength of Caustic.

(6) The grams of NaOH per 100 c.c. of cathode liquor increased rapidly with increasing current density. At an anode flow of 25 c.c. per minute the grams of NaOH per 100 c.c. increased from 0.26 to 7.8 as current density rose

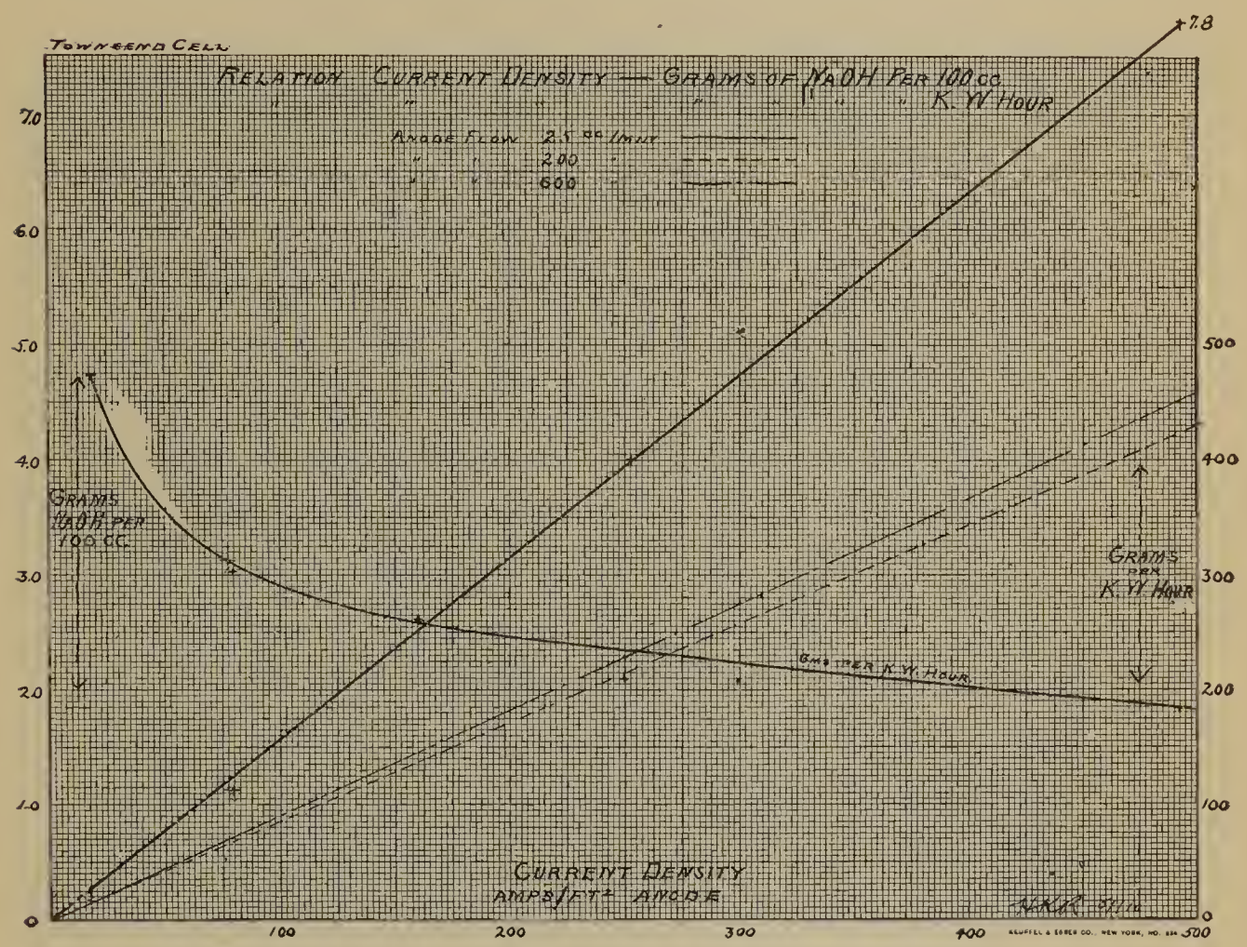


FIG. 6.

from 20-500 amperes per sq. ft. (2.2-55.5 A. per sq. dm.). Fig. 6.

(7) Increased rate of flow of anode brine appears to reduce strength of caustic produced. Table 12.

Output.

(8) The grams of NaOH produced per kw. hour decreased from 473 to 184 as the current density rose from 20 to 500 amperes per sq. ft. (55.5 A. per sq. dm.). Fig. 6.

(9) Increased rate of flow of anode brine has little effect upon output per kw. hour. Table 12.

Observations.

(1) During run we had one explosion of fairly violent nature, due to bad contact.

(2) The anode surface is too small; should be increased to three times present area.

(3) The loss of voltage in contact, anode bar to anodes, was too

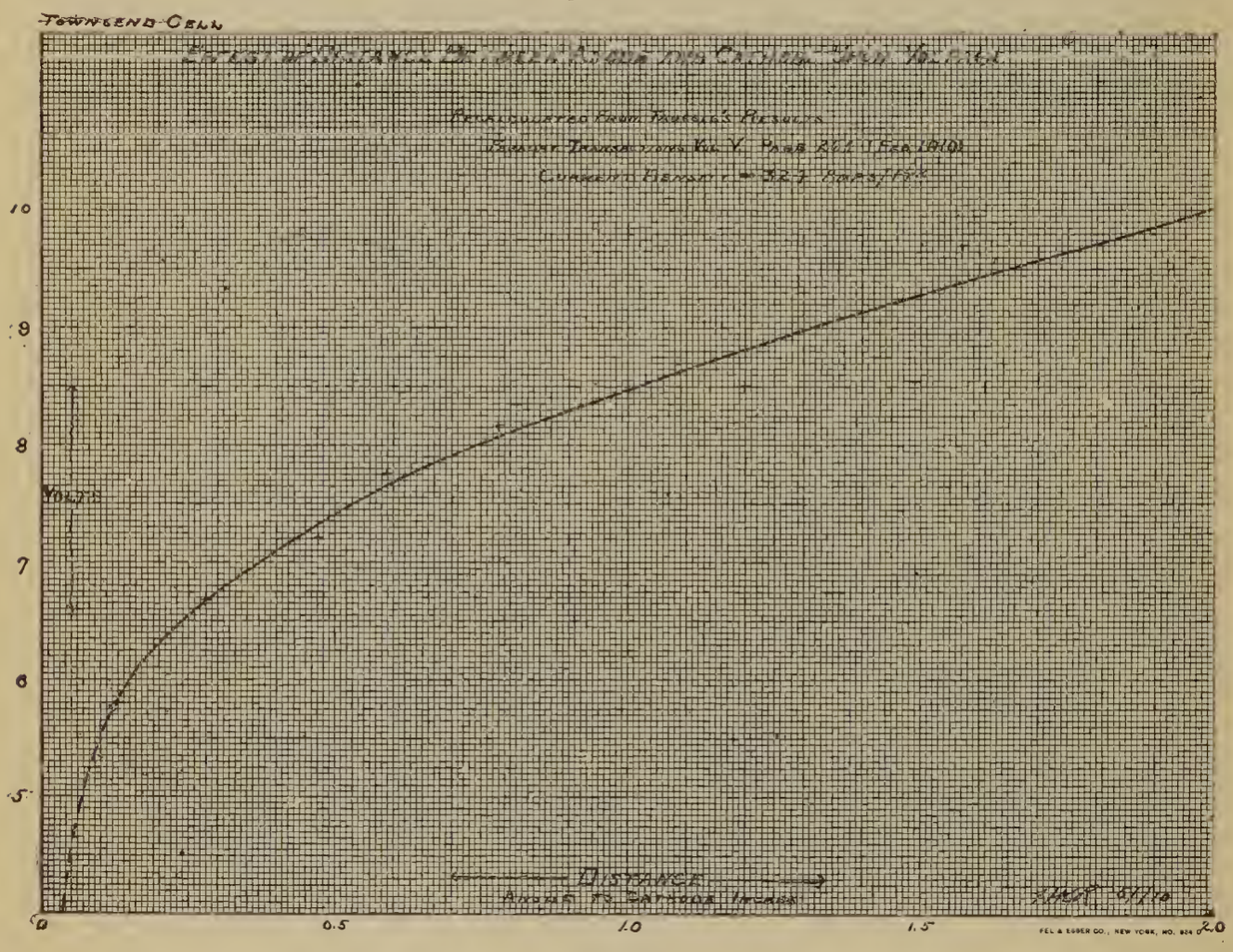


FIG. 7.

great. Larger bar and electrodes are necessary to reduce the heating occasioned thereby.

(4) The distance between anode and cathode is too large. It should be reduced to ½ in. (1.2 cm). To obtain an idea of the effect of this distance, reference is made to Fig. 7, taken from February, 1910, number of the Faraday Transactions.

(5) The lead goose-neck continually gave trouble, and should be replaced by iron pipe.

CONCLUSIONS.

(1) *Increasing Current Density*

(a) Decreases:
  (1) Current efficiency.
  (2) Energy efficiency.
  (3) Grams of caustic produced per kw. hour.

(b) Increases:
  (1) Voltage.
  (2) Temperature rise and operation.

(2) *Increasing Rate of Anode Flow*

(a) Has little or no effect upon:
  (1) Current efficiency.
  (2) Energy efficiency.
  (3) Product per kw. hour.

(b) Appears to decrease strength of caustic liquor.

(3) *The cell should be re-designed, giving attention to following points:*

(1) Increased anode surface.
(2) Larger anode conductor bar.
(3) Less distance, anode to cathode.
(4) Pocket for cathode liquor.

Electrochemical Engineering Laboratory,
Pennsylvania State College,
May, 1910.

DISCUSSION.

MR. A. H. HOOKER: I have had considerable commercial experience in a plant producing 20 tons of caustic per day, with the following results: Using ½ inch between the electrodes for operation much less voltage is required than with the distance at which Mr. Richardson operates. The cathode plate

in the Townsend cell has a large number of perforations, many times as many as in the plate used by Mr. Richardson. With his smaller number of perforations his caustic must flow back into the decomposition chamber and so reduce the efficiency. The oil line on the Townsend cell is at a different point from that on Mr. Richardson's, and it is important that this oil line be properly placed or the highest efficiency will not be obtained. Using a current density of 160 amperes we have operated continuously at 4 volts and at an efficiency of 96 percent, producing liquor containing 15 grams NaOH per 100 c.c. Mr. Richardson's results are very creditable, considering the circumstances under which he made them, but they do not represent the results obtained in commercial practice on a large scale.

If we examine the curve of current density and voltage and compare Taussig's results obtained with iron we find that we can double the current density, using only one and one-half times the voltage.

CHAIRMAN BAEKELAND: Mr. Townsend's original idea was to take out the caustic and resubject it to electrolysis. He used a parafine oil and found in practice that high current density was favorable to the action of the cell because of the scrubbing action due to the evolution of gas.

A paper read at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 7, 1910, President L. H. Backeland in the Chair.

THE WHITING ELECTROLYTIC CELL

By Jasper Whiting.

The Whiting Electrolytic Cell is the result of an attempt to improve that type of apparatus which employs mercury as an agent in the electrolytic decomposition of alkali chlorides.

It has long been recognized, I think, that the mercury type of cell, from the purely theoretical standpoint, is the best thus far conceived, chiefly because it is free from diaphragm troubles and produces in one operation pure caustic alkali. When one considers, however, that the first mercury cell was invented more than twenty years ago, that the patent office is full of patents covering cells of this kind, and that there has been, up to the present time, only one successful process, the Castner, in commercial operation in this country, it is easy to believe that while the idea is simple, there must be innumerable difficulties in the way of the successful operation of mercury cells.

Moreover, while certain mercury cells seem to work well on a small scale, the results are difficult to duplicate in a plant of commercial size. Rhodin, for instance, was successful enough with his small apparatus to sell his patents for half a million dollars, but the plant he erected at Sault Ste. Marie was a total failure. The Bell Brothers also exhibited successful models, but the Pennsylvania Salt Company lost $75,000 in an attempt, ending in failure, to make the process work on a commercial scale.

Also, the Baker cell had some success in the laboratory, but when the West Virginia Pulp and Paper Company attempted to operate it in connection with one of its paper mills, it soon proved a failure.

Moreover, a well-seasoned apparatus in the hands of men inexperienced in the idiosyncrasies of mercury and sodium amalgam has never been a success. This is instanced by the fact that the Japanese, though possessed of all the published knowl-

edge of the Castner Company, and with all the rights to use the Castner patents, lost $100,000 before the unsuccessful attempt to make bleach and caustic soda by the Castner process in Japan was abandoned. On the other hand, the Castner process is one of the most striking successes of the whole electrochemical field.

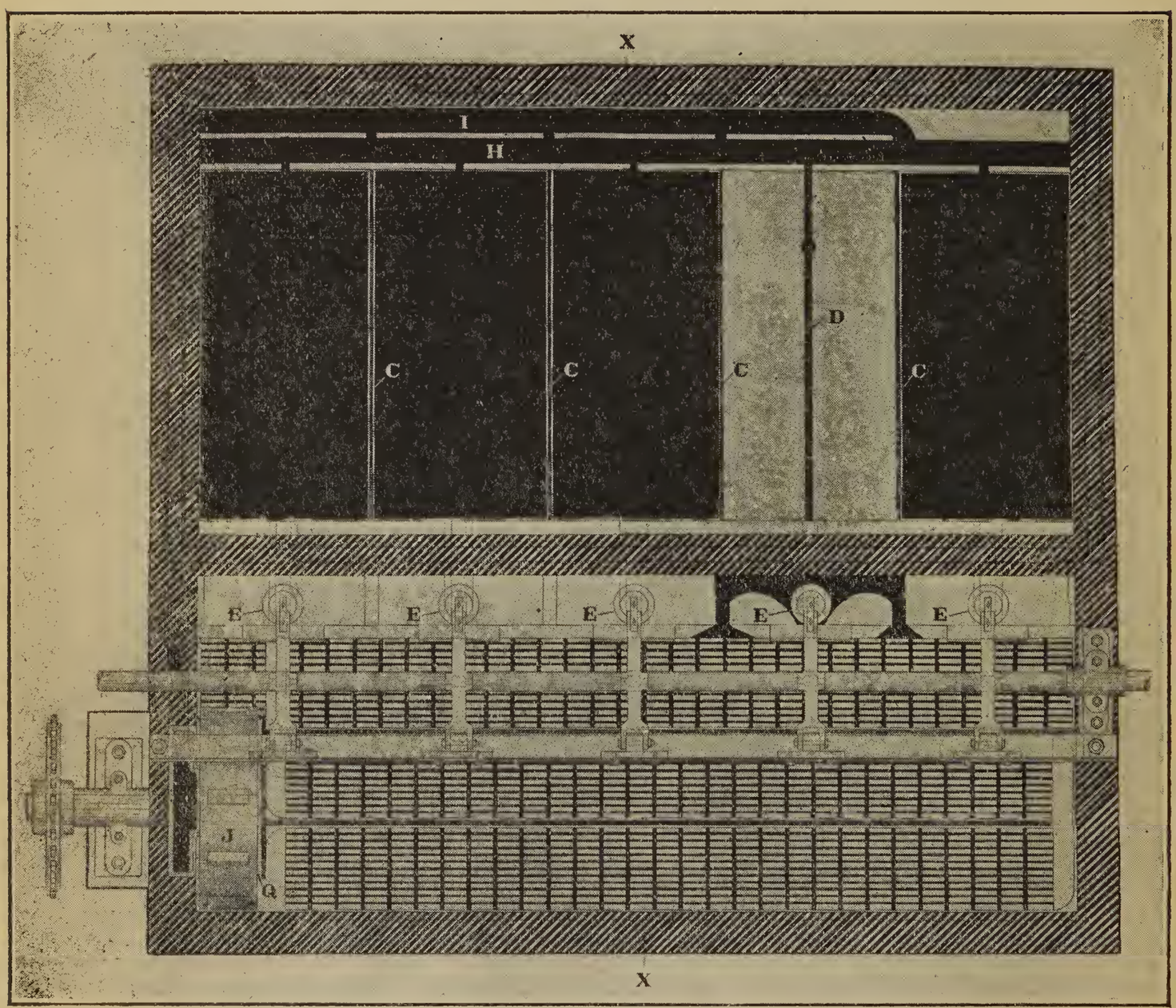


FIG. 1. Whiting Electrolytic Cell Plan.

The company has a very large plant at Niagara Falls, and other plants in Europe, and has been paying dividends on its capital for many years. The fact is that sodium amalgam is a most elusive and contrary material. In the language of a man well qualified to judge, it "defies all the laws of nature."

The chief stumbling block in the way of the successful operation of mercury cells is the difficulty of removing the sodium amalgam in a uniform and continuous manner from the decomposing chamber, where it is formed, to the oxidizing chamber. If this amalgam is not so removed, it tends to accumulate in the decomposing chamber until, when a certain concentration is attained, violent secondary reactions are set up with consequent lowering of the efficiency of the cell. In the ordinary type of apparatus the mercury is caused to flow in a wide and shallow channel from one compartment to another. Hydraulic engineers have long recognized the fact that when a stream of water flows through such a channel, the liquid travels much more rapidly in the center than on the sides, because the friction of the walls of the channel holds back the material adjacent thereto. If this is a serious difficulty with such a simple fluid as water, it is doubly true of a complex fluid such as mercury and its overlying stratum of sodium amalgam. As a result, the sodium amalgam tends to accumulate to an excessive degree, with consequent lowering of the current efficiency.

In the Whiting cell a principle new to this type of apparatus is employed for the purpose of overcoming the above difficulty. This cell operates intermittently. A body of mercury is placed in the decomposing compartment and held there in a stationary position as regards the anodes for a given length of time, during which sodium amalgam of the desired concentration is produced. This amalgam is then completely drawn off from the decomposing compartment, and when removed its place is taken by another body of mercury free from sodium. By placing a number of these compartments in parallel, and operating them successively, the cell, while intermittent in principle, is continuous in its action.

The Whiting Cell is a massive concrete structure, supported on four concrete pedestals, but insulated therefrom. It consists of a shallow receptacle, or box, divided into two compartments, *A* and *B*, by a concrete partition. The bottom of the larger, or decomposing compartment *A*, is divided by low glass partitions *C* into a number of sections. The sections have V-shaped bottoms, sloping at a slight angle towards central slots *D*, these slots being carried through the dividing concrete partitions into the smaller or oxidizing compartment *B*, where they turn upward and are

closed by poppet valves *E*, operated by cams *F*, attached to a slowly revolving shaft *G*. The other ends of these slots are connected one with another by means of a common channel *H*, called the distributing level, and this channel connects in turn with a secondary channel or run *I*, which leads through one of the side

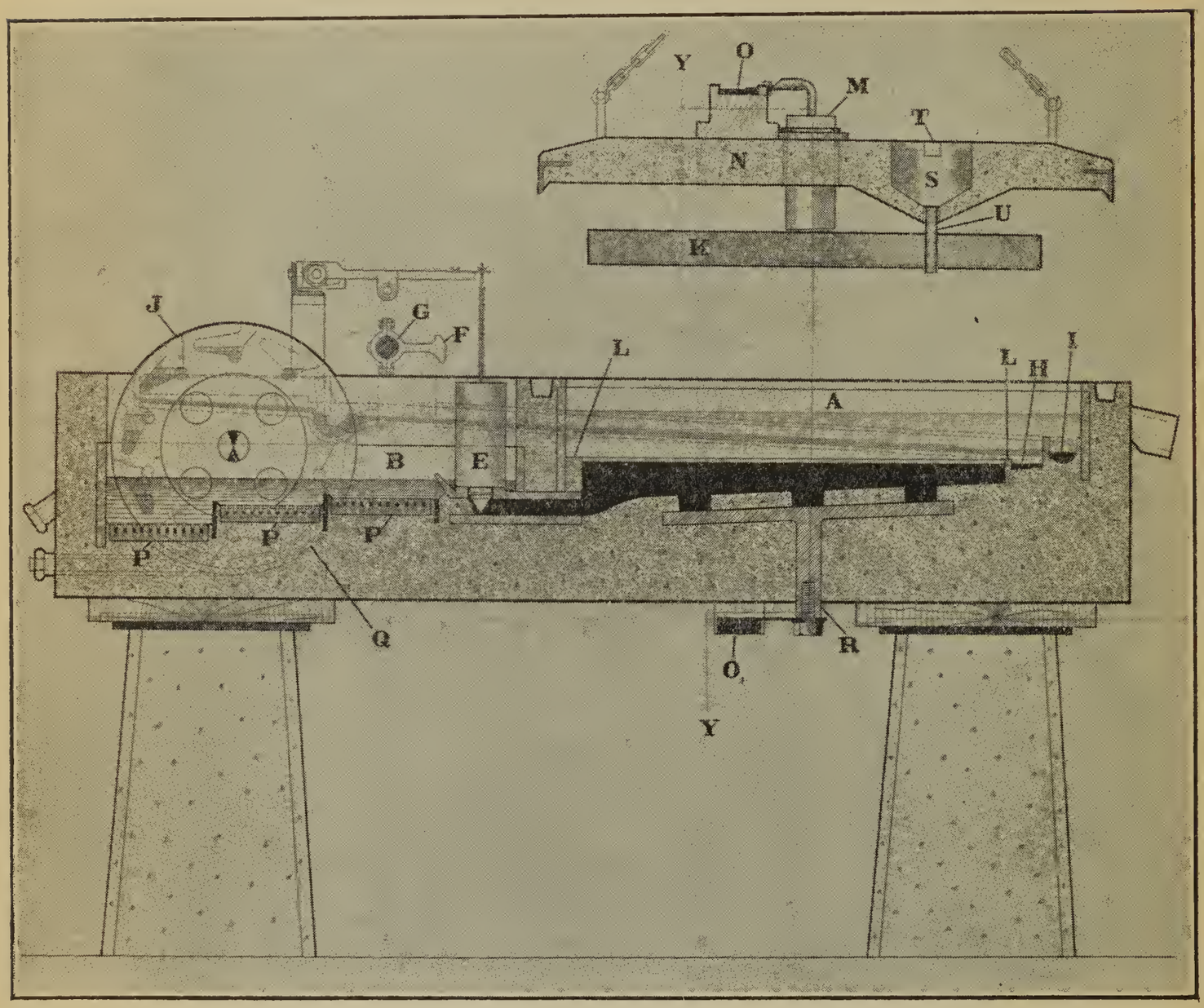


FIG. 2. Whiting Electrolytic Cell. Cross-section.

walls of the cell to a pump *J*, at the extreme end of the oxidizing compartment. Mercury covers the bottom of the decomposing compartment, filling to a common level the several sections above described. The anodes *K*, consisting of slabs of Acheson granite, perforated to permit the free discharge of chlorine, rest upon ledges *L*, placed at the ends of the sections in such a way that the

distance between the electrodes shall be a minimum. To these anodes are fastened graphite leads *M*, which extend upwards through the cover *N*, connecting with the busbar.

The oxidizing chamber is divided into three channels *P*, lined with graphite of special design, and sloping successively downwards to form a ziz-zag path to the pump-pit *Q*, where a stoneware rotary pump *J*, also of special design, is placed, and operated by auxiliary means. A common body of electrolyte, brine, fills the decomposing chamber, and water, or caustic, the oxidizing compartment.

The action of the cell is as follows: The floor of the several sections of the decomposing chamber is covered with mercury, which is maintained at a common level by means of the distributing level. The current, supplied to the anodes from the busbars, flows through the brine solution to the mercury and out through the bottom of the cell through iron rods *R*, partly imbedded in the concrete and serving to connect the mercury in the cell with the cathode busbar.

The current passing through the electrolyte decomposes the brine, chlorine is given off at the anodes, escaping upwards, and sodium is separated at the surface of the mercury, amalgamating therewith. When this action has proceeded for a predetermined period of time, approximately two minutes, the poppet valve at the point of exit of one of the sections is opened by the action of the cam, and the entire mass of sodium amalgam contained in that section sinks rapidly into the slot and down through the connecting pipe into the oxidizing chamber. The period required for the emptying of a section having been accurately determined, the design of the cam is such that when the mercury is all out of the section the valve closes. Mercury free from sodium then flows into the empty chamber by way of the distributing level, and continues to flow until the common level is established. In the meantime the sodium amalgam in the oxidizing compartment flows by gravity successively over the graphite plates, and in so doing is freed from the sodium it contained, only pure mercury reaching the pump-pit, this pure mercury being then raised by the rotary pump into the wall pipe of the decomposing compartment, through which it flows by gravity to the distributing level. Thus is the cycle completed.

By operating the sections successively, the action of the cell is, in effect, continuous, though the action of each individual section is intermittent.

It is easy to see the advantages of the electrical conditions in the decomposing compartment. A body of mercury is placed in a stationary position as regards the anodes, and at such a distance from them as is theoretically the best; therefore, the distribution of the current is uniform and the resistance of the

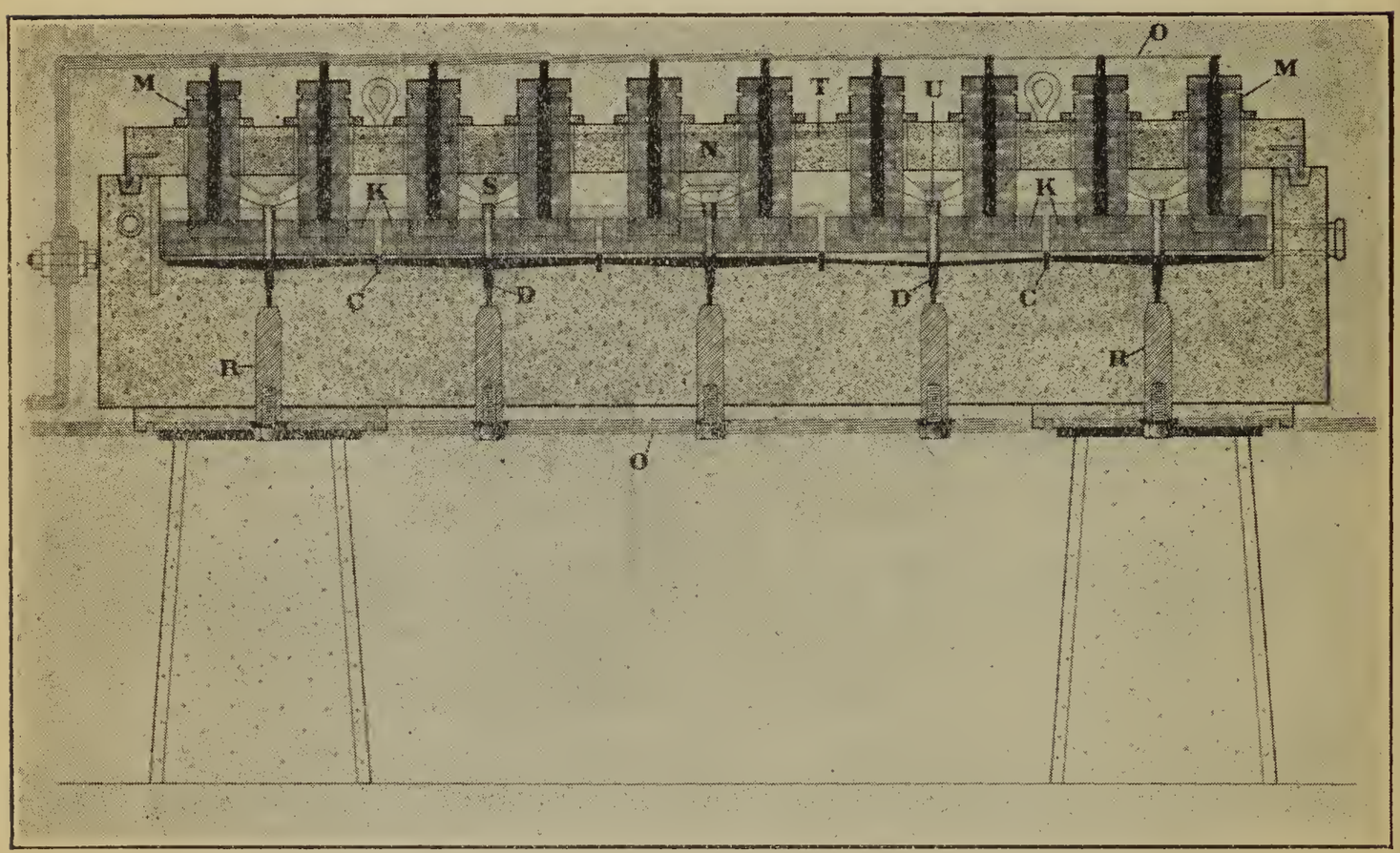


FIG. 3. Whiting Electrolytic Cell. Longitudinal Section.

electrolyte a minimum. Moreover, as there is no agitation of the mercury during the period of electrolysis, secondary reactions are not facilitated, and as the initial primary conditions are re-established at frequent intervals, uniformity of operation is maintained.

In order to operate the cell satisfactorily, it is necessary to feed brine of great strength uniformly between the electrodes. As the electrodes are very close together, and as the area of the cell is considerable, this appeared at first to be a serious difficulty. The problem was solved by utilizing the intermittent action of the mercury in the sections to control the operation of a device for

feeding the brine. Cup-shaped receptacles *S*, equal in number to the sections of the decomposing chamber, are formed in the cover *N* of the decomposing compartment, these receptacles being connected by a common channel *T* at their upper extremites. Through the bottom of these cups, glass tubes *U* extend downward between the anodes, the end of each tube terminating below the surface of the mercury, at a point near the middle of each section.

Brine is fed into one of these cups from an outside source, and when the cup is full the brine overflows into the channel, filling each of the cups in turn. As long as the sections are filled with mercury, the bottom of the tubes are sealed, so that no brine can flow into the cell; but as soon as the mercury is withdrawn from one of the sections the seal is broken on the corresponding tube, and a definite quantity of concentrated brine, corresponding to the size of the cup, flows into that individual section. As this brine has a greater specific gravity than the partly electrolyzed brine in the cell, it sinks to the bottom and spreads laterally, forming a layer about 1/16 inch (1.56 mm.) thick over the glass plates. When the purified mercury again fills the section, the new brine, free from chlorine, acts as a protective layer to it, and is in its proper position for being electrolyzed. Moreover, as the brine enters the cell at a time when the section is empty, it causes no agitation of the mercury, and consequently facilitates no secondary reactions.

The action of the oxidizing chamber of the cell could hardly be more simple, and it has the distinct advantage of being automatic. The graphite slabs are so designed as to form a large number of channels through which the mercury flows. The sides of these channels extend upwards into the caustic solution, and form, with the amalgam, a galvanic couple, which serves to decompose the amalgam. The principle of this action is by no means new, but so far as I know it has never been successfully employed in an electrolytic cell until now. The difficulty lay in maintaining a proper contact between the amalgam and the graphite. It is easy to secure contact at first, but after the action has proceeded for a varying length of time, the graphite tends to become polarized by the hydrogen given off at its surface, until the necessary contact between it and the amalgam is destroyed.

We have overcome this trouble by means of a very simple device. Holes about one-eighth of an inch in diameter and one-half inch deep are bored at frequent intervals in the graphite slabs, and these holes are filled with pure mercury before starting to operate the cell. This pure mercury makes, of course, an effective contact with the graphite walls of the holes, especially as it is under a relatively high head, and, as it is also in contact with the sodium amalgam which flows above it, it forms a con-

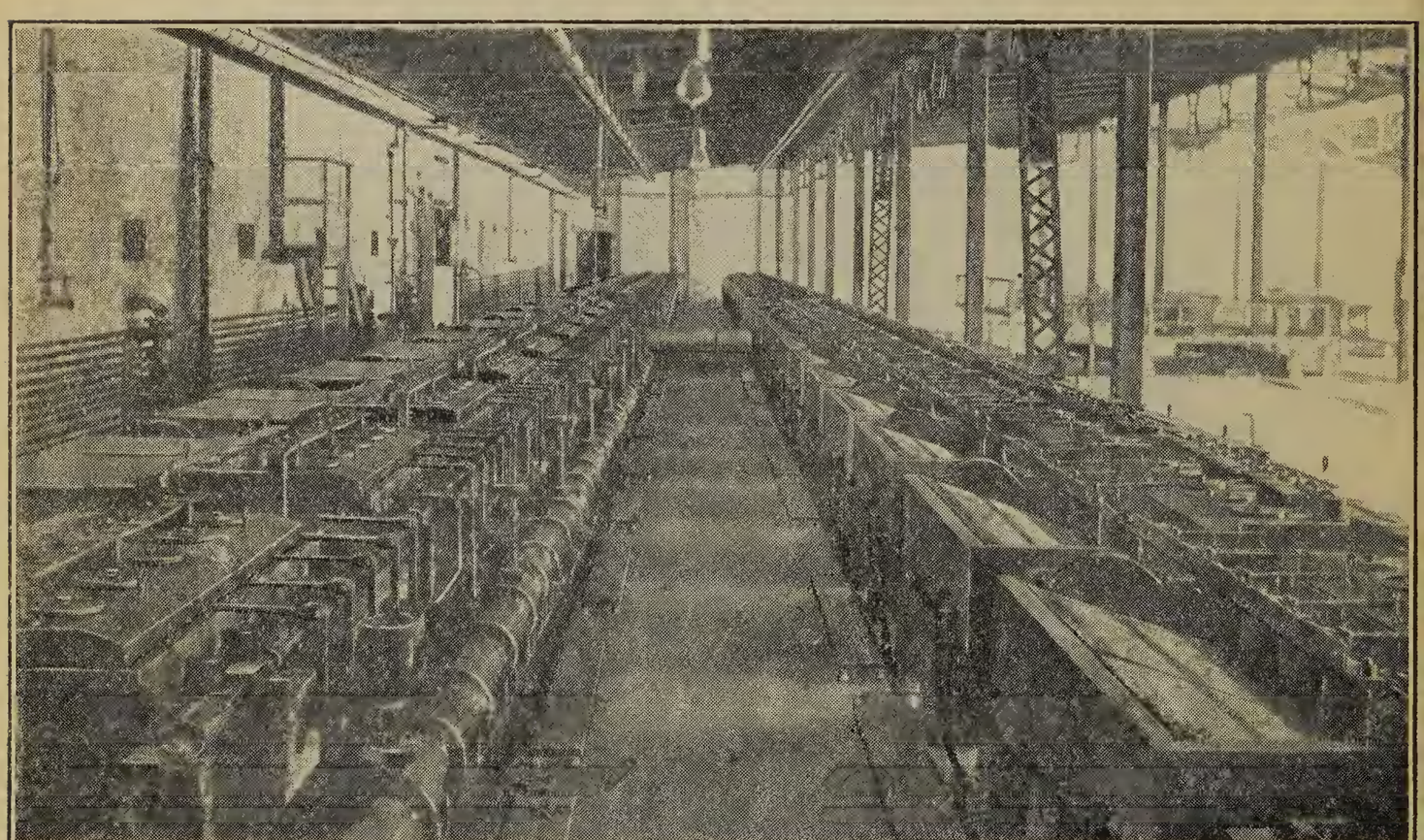


Fig. 4. Whiting Electrolytic Cell. Installation of Oxford Paper Company.

necting link between the sodium amalgam and the graphite. Moreover, as sodium amalgam is lighter than mercury, and as the holes are narrow and deep, there is little tendency for the sodium to diffuse downwards; consequently the mercury in the holes remains pure, and, as there is no action between it and the graphite, there is no serious polarization of the walls of the holes, and, as a result, the original contact between the mercury and the graphite is not destroyed.

In practice, this galvanic action proceeds at a very vigorous and uniform rate until all the sodium in the amalgam is oxidized,

when it automatically stops, pure mercury being delivered to the rotary pump to be returned to the decomposing chamber.

This method of oxidizing amalgam is superior, I think, to that employed in any other cell operating on a commercial scale. It requires no attention, being at all times automatic, and is free from mercury losses. Caustic of almost any desired concentration may be produced. It is only necessary to regulate the amount of water fed into the chamber to produce the strength desired. The caustic formed is, as already stated, practically pure.

One of the features of the Whiting Cell is its accessibility. This is largely by reason of the construction of the cover of the decomposing compartment. This cover is made of reinforced concrete, with edges extending downward to loosely fit into channels made in the top of the wall of the decomposing compartment, thus forming a gas-tight, liquid seal. The anode leads extend upwards through the cover and, while removable, are so arranged that when the cover is raised, the anodes are raised also. To the cover, likewise, are fastened the busbar and the system for feeding the brine; consequently, when the cover is lifted, all the auxiliary apparatus in connection with the decomposing chamber of the cell is removed in one operation, permitting a rapid inspection and cleaning of the cell.

There is, of course, no fixed limit to the size of the Whiting Cell. As each section works independently, one from another, the sections may be multiplied in number as desired, until a cell of capacity suited to the conditions is produced. The cell which has been developed at the plant of the Oxford Paper Company, at Rumford, Me., is about 6 feet (1.8 meter) square over all. It contains five sections, and is operated with a current of from 1,200 to 1,400 amperes, equivalent to a current density of over 100 amperes per square foot (11 A. per sq. dm.) of active anode surface. The voltage across the terminals is approximately 4, and the cells operate at a current efficiency of from 90 to 95 percent.

The Whiting Cell is, I think, the only cell which can be shut down without noticeably affecting its efficiency, or without injury to the apparatus. To illustrate this in a practical way, during a test run of two weeks' duration, in our preliminary experimental plant of four cells, the current was shut off for various reasons

eleven different times, for periods varying from a few minutes to twelve hours, but, in spite of these many shut-downs, the plant maintained an average current efficiency of over 95 percent. In case of shut-down it is only necessary to stop the operation of the pump, when all the mercury is automatically drawn off from the decomposing to the oxidizing compartment, where it remains until it is again desired to start the cell, which is accomplished by the starting of the pump. As the mercury is all out of the decomposing compartment while the current is off, there is no loss of mercury due to the corrosive action of the chlorinated brine, as is the case with other types of mercury cells.

Moreover, the Whiting Cell is singularly free from injury on account of accidents. Should there be an unexpected stoppage of the pump, the mercury leaves the decomposing chamber as above described. Should one of the valves leak, the level of the mercury in the decomposing chamber will be slightly affected, with a corresponding increase in voltage, but no serious damage will be done. Should one of the valves fail to operate, sodium would accumulate in the mercury of that section, but the remainder of the cell would operate satisfactorily. Occasionally, the cell has to be washed, to free it from precipitated graphite dust, and from slime which forms on the glass plates. The operation of washing a cell is, however, an extremely simple one, and requires the labor of but one man for about half an hour.

As the cell is operated at a temperature below 40° C., the tendency to form chlorates is very small, and consequently the deterioration of the graphite anodes is reduced to a minimum. There is, of course, no depreciation of the graphite slabs in the oxidizing chamber of the cell.

As before stated, the mercury type of cell produces pure caustic. Consequently, our cell efficiency, as far as the caustic is concerned, is our plant efficiency. There are no losses incident to subsequent treatment. What flows out of the cell is our finished product, assuming, of course, that liquid caustic is sold. The chlorine gas escaping from the cell is 98 percent pure, the remaining 2 percent being hydrogen, and, as the chlorine leaves the cell at a relatively low temperature, it is unnecessary to cool it further before using it to form bleaching liquor.

The Whiting Electrolytic Cell is not an expensive cell to install.

It is generally believed that mercury cells are very costly, for the reason that large quantities of mercury are required in their operation, and mercury is, of course, a high-priced material. When one considers, however, that the use of mercury eliminates the necessity of installing very expensive and rapidly deteriorating multiple-effect evaporating machinery, and auxiliary apparatus for the purification of the caustic produced in diaphragm cells, it is easy to see that one expense largely off-sets the other. Moreover, mercury is a quick asset convertible into cash at a high proportion of its first cost, whereas second-hand machinery is of little value. It is my belief that a plant of a given capacity employing the Whiting Electrolytic Process would not cost materially more than a plant of similar capacity employing any one of the present available diaphragm processes.

The present plant, erected for the Oxford Paper Company, has a capacity in bleach liquor equivalent to about five tons of bleaching powder per day, and produces, in addition, about two tons of pure caustic soda. This plant has been operating since early in January, and the results obtained from it have been so satisfactory that its capacity is now being increased five times.

I desire, in ending this paper, to acknowledge the aid rendered in the development of the Whiting Process by Mr. William Hoopes, of the Aluminum Company of America; by Mr. W. R. Mott, who served for a few months as my assistant, at the time I first began experimenting; by Prof. C. F. Burgess, of the University of Wisconsin, who furnished valuable suggestions at a later stage in the cell's development; and by Mr. A. M. Hamblet, the present superintendent of the plant at Rumford, whose assistance during the past two years has been most valuable.

DISCUSSION.

PROF. C. F. BURGESS: I have observed Mr. Whiting's cell in its development, and have been impressed with the wide difference between a laboratory experiment and a commercial operation; also particularly with the "unlawful" behavior of sodium

amalgam and chlorine. I hope some day that Mr. Whiting will give us a paper on "Some troubles I have met and how I overcame them."

CHAIRMAN BAEKELAND: All electrolytic cells work better in a laboratory than in practice; one can easily change the details of operation in a laboratory apparatus, but it may cost thousands of dollars to interrupt operation in a factory plant. I believe almost every one of us at some time or another of his life, has invented some electrolytic cell. Fortunately, the development of most of these inventions has been arrested before hundreds of thousand dollars have been spent upon it. The fact that the cell described by Mr. Whiting is used in practice, increases considerably the value of his communication.

I would like to ask Mr. Whiting how many pounds of mercury he uses to a cell of 2,000-2,500 amperes, and also whether any losses of mercury occur during prolonged operation? What is the strength of the cathode liquor obtained from the cell and how often do the cells have to be washed?

MR. JASPER WHITING: We use 350-375 pounds of mercury per cell, equivalent to 3,500-3,700 pounds per ton of bleach made per day. There is constant loss due to the solubility of mercury in the alkali and brine solutions, but this only amounts to approximately 2 percent of the total per year. There are, of course, other losses, due to the mechanical handling, etc., which might bring the total up to 6 percent per year. We have figured on 10 percent in our estimates in order to be conservative.

The caustic solution as produced at present contains 20 percent sodium hydrate. We have made it up to 40 percent, and even more concentrated solutions can be made, we believe, if desirable. The frequency of washing varies with the conditions of operation. I should say that the cover of the cell is raised once a month on the average.

CHAIRMAN BAEKELAND: A rich cathode liquor is quite desirable, and if Mr. Whiting can produce easily 40 percent solutions, this is a decided advantage for many purposes where no further concentration is necessary. The frequency of washing his cell corresponds about to that of the better class of the diaphragm cells.

DR. J. W. RICHARDS: Is there any loss of mercury by vaporization or by carrying off as vapor by the evolved hydrogen. Have any effects of salivation been noted on the workmen?

MR. WHITING: The mercury in our cells is always covered with solution and therefore cannot vaporize. We have experienced no trouble whatever with the possible evil effects of mercury vapor upon our workmen.

CHAIRMAN BAEKELAND: How much hypochlorite or chlorate is formed in your anode compartment?

MR. WHITING: We have determined the amount, but I have no figures relating to this matter with me. We make a strong brine and use it in a closed system until the hypochlorites, sulphates, etc., become too concentrated, when we then throw it away and start anew. We have not yet determined how often this is necessary, but this varies a good deal with the purity of the brine and with other conditions. The impure liquor is thrown away, as it costs more to purify it than it is worth.

CHAIRMAN BAEKELAND: If chlorates and hypochlorites occur in considerable quantities in the anode liquor, they are continually electrolyzed in their turn, and form oxygen at the anode; after a certain percentage of these oxysalts has been reached, they remain constant. The loss of current in electrolyzing these compounds is small, but their chief drawback is the corrosion of the graphite anodes.

The anode questions is a very serious one, because anodes form a large item in the cost of these processes. Dr. Acheson rendered a great service in furnishing the electrolytic industry with graphite electrodes, which are more lasting than the older carbon electrodes. Platinum is too expensive to use. Graphite anodes are less expensive, but they corrode; in laboratory experiments this corrosion may be small, but in practice, where large groups of cells are run by ordinary workmen instead of by experts, if ONE cells runs badly the circulating electrolyte vitiates the whole brine system and lowers the efficiencies in the cells and causes corrosion of the anodes. At the end of the year the books show high anode costs. The corrosion of the anodes not only causes a loss of anodes but increases the internal resistance by disarranging

the cell conditions, especially as far as distance between electrodes is concerned. For instance, if the cells have been designed for a working distance of 3/8 inch between the anode and cathode, after corrosion the ends and faces of the anodes will become very irregular and cause very different current densities at different parts; with the results of producing very different electrolytic conditions from those for which the cell was designed. Such small details as these are of the greatest importance in commercial work, and frequently decide the practical value of a cell.

Dr. Richards: Would a paraffined graphite electrode, such as Mr. Turrentine uses in his electrical analyses, decrease the corrosion?

Chairman Baekeland: We have tried paraffin on graphite anodes but it is quickly attacked by chlorine. In Germany other anodes have been tried, such as cast iron oxide electrodes. These resist chlorine, but there seems to exist some difficulty in producing this kind of anode.

Mr. Whiting: We do not paraffin our anodes. We have tried paraffining them, but without success.

Chairman Baekeland: In commercial operations such small details as proper connections for the anodes may give much trouble, and often devices which look clumsy on first sight give better results in practice than connections designed with much care and forethought and which, notwithstanding their apparent superiority, cause bad contacts and increased voltage. It has happened that a cell however carefully planned in principle lost its advantages by some such seemingly trivial detail.

A paper read at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 7, 1910; President L. H. Baekeland in the Chair.

SOME CHARACTERISTICS OF THE MODERN DRY CELL.

By D. L. Ordway.

About the year 1890 there appeared on the market in this country an improvement over the old zinc, carbon, sal-ammoniac wet cell. Its form was similar to that of the present dry cell, but its action was very materially different. Many of you probably had experience with the early dry cells similar to those of the writer, who, after trying one after another of them, finally threw them all out and returned to the old reliable "wet cells."

By 1897 the manufacture had attained a considerable volume in Europe, and it was in that year that an American company first put on the market an efficient and reliable dry cell. It was, as nearly as it could be made, a copy of one of the best French cells, and it sprang into immediate favor for telephones, door bells and for the ignition of the then newly-invented automobile engines, so that by 1900 this one company was turning out over a million cells per year.

Since that time the use of the dry cell has increased with great rapidity, due to the fact that they are now made both uniform and reliable, until it has practically superceded that of the old sal-ammoniac wet cell, and the dry cell is used wherever electrical energy is desired in small quantities at a low price and in packages of convenient size and portability. It has a great variety of uses, the chief of which are as a source of energy in telephones and for the ignition of gas and gasoline engines. In spite of the introduction of the central-energy telephone exchange and of magneto-ignition, the production of dry cells has increased continually and very rapidly, until there are now probably 50,000,000 made annually in this country alone.

A large majority of these cells are cylindrical in shape, 2.5 inches (6.25 cm.) in diameter and 6 inches (15 cm.) high.

Besides these, which may be considered as standard cells, comparatively small numbers of cells of various sizes and shapes are made from the 3.5 by 8 inch (8.75 by 20 cm.) on the one hand, to the 0.62 by 2 (1.5 by 5 cm.) on the other. Cells are made square, oblong and oval, and are sold either separately or connected into batteries ready for use. There are also on the market various sorts of so-called reserve cells, which are inert until put into service by the addition of water, heating, or the putting together of parts which are kept separate until used in order to prevent local action.

With these few words of introduction we will pass at once to a very brief sketch of the construction of the dry cell, and then to a discussion of its chief electrical properties, its uses, and the methods that have been developed for testing it for the different types of service on which it is most often employed.

GENERAL DESCRIPTION OF THE MODERN DRY CELL.

So complete a general discussion of the manufacture of the dry cell was presented before this Society last year that it will only be necessary to pause at this point in order to briefly note some of the principal variations in its construction.

The Jacket or the outside insulation is usually a simple round carton made of pasteboard or chipboard. It is sometimes carefully water-proofed by means of paraffin or pitch, and some cells are on the market in which the jacket is made an integral part of the cell by being extended a short distance above the zinc container and then filled to its upper edge with the sealing compound.

The Negative Pole or zinc container is usually made cylindrical, and, in this country, 2.5 inches in diameter by 6 inches (6.25 by 15 cm.) high. This size has become the standard, both because it is convenient to handle, and because its parts are better related to each other chemically and electrically than other sizes. The thickness of the zinc used varies from 0.012 to 0.022 inches (0.3 to 0.55 mm.), according to the size of the cell and, to some extent, to the service for which it is intended. Among the changes from the standard which are occasionally met with are zinc containers without bottoms, in which cylinders of zinc open at each end are set into layers of pitch in the bottoms of the jackets, and

double zincs one inside of the other with a lining between, which are intended to be so arranged that when the inside zinc is dissolved, the electrolytic action is transferred to the outside one and the life of the cell increased. The shape of the container is almost universally cylindrical, because it is cheaper to make cells of this shape. Until within the last few years the zinc was often amalgamated, but this process has been found to add little to the value of a cell that is otherwise well made. The zinc is usually painted on the outside surface with an insulating layer of paint, which serves as an additional protection against short-circuiting when cells are connected in series.

The lining of the zinc can is an insulating absorbent layer, which serves as a reservoir for electrolyte and as a means of separating the positive from the negative pole of the cell. It is usually made of special grade of pulpboard, which is manufactured for the purpose under conditions which reduce the possibility of the presence of materials which would be harmful to the finished cell. Each lot received is carefully tested, and accepted or rejected according to its conformability to definite specifications. Besides the above, cheap pulpboards, blotting papers, etc., are sometimes used, but not in high-grade cells.

It was formerly often the custom, and some manufacturers still make dry cells in this way, to use a paste containing starch and plaster of paris as a part of the lining. By this process the filling material was pressed around the positive electrode by hydraulic pressure and then, usually after being wrapped in blotting paper, the whole was set into the zinc can, into which some of the paste had been poured while in a liquid condition. The filling material and electrode were held in place until the paste had set, after which the cell was sealed and considered finished. In at least one case, the paper or cloth lining was dispensed with entirely and the molded "filler" was set into the paste without any other means of preventing internal short-circuits between the filler and the sides of the zinc than the hardened paste. This method has been largely discontinued because it cost more to make cells in this way without giving any extra advantage. Dry cells have also been made in which the lining consisted of a layer of cheesecloth surrounded by a viscous pasty liquid containing the electrolyte and a large amount of starch. Cells made

in this way are apt to leak in service and become covered with a disagreeable pasty mass which is unsightly and liable to cause short-circuiting of cells connected in series.

The filling material is packed into the zinc can between the lining and the carbon electrode, and is usually a mixture of manganese dioxide and carbon. The manganese dioxide, which acts as a depolarizer, has, in the best grade of cells, an oxygen content equivalent to 85 per cent. of more of MnO_2, and the carbon is usually a specially prepared material, made for the purpose of obtaining the exact combination of properties required in the finished cell. In either case, graphite is added to the carbon to decrease the internal resistance of the cell. Both natural and artificial graphites have been used, though the latter is more commonly employed.

In considering the filler, it must be borne in mind that it forms a part of the positive element of the cell, and that the surface of this element is not, as is sometimes considered, at the surface of the electrode, but at or near the outside surface of the filling material. More definitely, it is at the outer layer where a continuous carbon contact is obtained from the electrode outwardly through the filling material towards the lining.

In a very few cases dry cells have been made with mercuric chromate and other solid oxidizing materials in the "filler," but the use of this class of materials has not been followed by satisfactory results.

The Electrolyte is almost universally a solution of ammonium and zinc chlorides. Theoretically it might be thought better to omit the zinc chloride, as it would be natural to consider it a mistake to add the very ions which were to be produced by the action of the cell. Practically, however, it has been found necessary to do this in order to prevent action when the cell is not on service, and in the present state of our knowledge of the subject the zinc chloride cannot be omitted.

The Electrode, or, as it may be called, the current collector, is invariably a rod of carbon. It is sometimes cylindrical and sometimes more or less fluted in shape; not, as is often stated, to present more surface to the action of the electrolyte, but merely

to hold the electrode more firmly in its place and so decrease the loosening tendency which rough handling sometimes develops in round electrodes.

The Seal is simply a pitch composition which is poured on the top of the cell to prevent the filling material from loosening and the cell from drying out by evaporation.

Besides pitch compounds, such materials as sealing wax, resin, asphalt and petroleum residues have been used as seals.

The Connectors finish the cell, and need little comment. They are usually of the familiar "binding screw" type, but in some cases little springs are used, which grip the connecting wires firmly and hold them with constant pressure, so that jarring cannot loosen them.

All of the material going into the manufacture of dry cells is selected with the greatest care, and complete testing laboratories are maintained whose function it is to see that each shipment of raw material destined for the dry cell is carefully tested and not accepted until it is known to be of a satisfactory standard of quality.

THE ELECTRICAL CHARACTERISTICS OF THE DRY CELL.

A very brief discussion of the principal electrical characteristics of the dry cell will now be taken up.

1. *Electromotive Force.* The electromotive force between a zinc and a carbon-manganese electrode in an electrolyte such as we have described is approximately 1.56 volts. In new cells of various types the value may vary from 1.5 to 1.6.

If a dry cell of the type now in general use is found with an open-circuit electromotive force materially less than 1.5, it is an almost certain indication either of serious deterioration due to age, or of the external short-circuiting of the cell, or of some defect, such as an internal short-circuit, which will soon render the cell unfit for service. Only an accurate volt-meter should be used to measure the electromotive force, for the cheap pocket instruments are often so inaccurate as to make their indications of open-circuit electromotive force worse than valueless. Pocket voltmeters can, however, be used to considerable advantage in determining the working voltage of a cell, because with that

value a small difference in the reading (say, 0.1 volt) does not make so great a difference in the conclusions that are to be drawn from it.

2. *Short-circuit Current.* Nine out of every ten dry cell users consider the short-circuit current as a direct measure of the value of the cell. This is probably true, because it is the only electrical property of the cell which can be easily measured with tolerable accuracy with the cheap instruments on the market, and because it decreases very rapidly when the cell is put into service, thus giving the impression of being a measure of service capacity.

In the hands of a person who is familiar with dry cells, there is no doubt but that a measurement of the short-circuit current may be made to give valuable indications of the condition of the cell, but when, as is too often the case, a purchaser considers the value of a cell as directly proportional to its ammeter reading, regardless of temperature or other conditions, the measurement becomes worse than useless to him.

At the present time most good dry cells in the standard 2.5 by 6 (6.25 by 15 cm.) size will give when new a short-circuit current of from 18 to 25 amperes. The cheaper grades give currents as low as, or even lower than, 10 amperes. In general, we may say that cells much above 25 or below 16 are to be looked upon with suspicion.

If the cell reads above 25 amperes, it is probable that an excess of low-resistance carbon has been added, thus reducing the percentage of manganese dioxide below what is required for the most perfect depolarization, while if it reads below 16 amperes, it is probable either that the cell has been made a long time, or that cheap materials were used in its manufacture.

That the short-circuit current is not a measure of the service capacity of the cell will be seen by an examination of Table I, where the short-circuit current and the service life of 24 brands of commercial dry cells are tabulated. The short-circuit currents are given in amperes, and the service life is expressed in ampere hours to a closed-circuit voltage of 0.5 when discharged continuously through 16 ohms resistance. It will be noted that there is little relationship between the short-circuit current and the service life in the case of the cells shown here.

Table I.

Short-circuit Current and Service Capacity of Dry Cells.

Brand of Cell	Short Circuit Current	Service Capacity
A	33.0	24.0
B	29.5	46.0
C	27.2	32.3
D	24.5	33.5
E	23.7	24.8
F	23.1	27.3
G	22.5	40.0
H	21.7	24.6
I	21.1	37.8
J	20.9	18.2
K	20.7	20.0
L	20.2	36.0
M	20.1	11.7
N	19.9	17.8
O	19.8	20.5
P	19.2	30.3
Q	19.2	38.6
R	19.1	19.1
S	18.2	27.1
T	17.4	43.4
U	16.5	36.5
V	11.6	13.6
W	9.7	16.0
X	6.6	4.5

At this point it may be again emphasized that the determination of the short-circuit current does not give a measure of the value of the dry cell. If a certain brand of cell usually reads 18 to 20 amperes, and an individual lot is found reading only 10 to 12 amperes, then it may safely be concluded that they are old or imperfect cells, but even in that case it would not be correct to assume that the service capacity of the cells had fallen proportionately to their short-circuit current. To show this clearly, we present in Table II the results of service tests and short-circuit current readings made on some new cells, and on the same lot when it was nine months old. The column headed "new cells" shows the two values on the cells when freshly made, and that marked "old cells" shows the same results taken nine months later. To obtain the service capacity, cells from this lot were discharged continuously through 2 ohms resistance to 0.25 volt closed-circuit voltage, and the results are given in ampere hours to that point.

TABLE II.

Short-circuit Current and Service Capacity of Old and New Dry Cells.

	New Cells.	Old Cells.
Short circuit current	22.4 amperes	3.6 amperes
Service capacity	24.9 amp. hrs.	20.2 amp. hrs.

In the measurement of the short-circuit current, care must be taken that the resistance of the outside circuit is constant for all tests made, or serious errors may be introduced. The so-called "pocket" ammeters which are sold for testing dry cells have short leads which form a part of the instrument and with which they are calibrated. The better instruments, such as the Weston, whose resistance is very low, must, however, be used with leads of a definite resistance. We have found that 0.01 ohm is a convenient value for the total resistance of the two leads, being practically equivalent to two 30-inch lengths of No. 12 lamp cord.

3. *Internal Resistance.* This is often considered as a definite, fixed value which determines the service capacity of the cell. It is usually determined by applying the formula $V—V^1/C$, where V is the open circuit and V^1 the closed circuit voltage and C the current flowing. It is evident, however, that this will give us a compound value composed partly of the sum of resistance of the different parts of the cell and partly of the resultant of the various electromotive forces in operation during the action of the cell. This resultant factor varies with the age of the cell, its degree of exhaustion, the temperature at which the measurement is made, and the current flowing. It is, therefore, idle to try to base any conclusion as to service capacity on a figure which is supposed to represent the internal resistance of a dry cell.

4. *Drop in Voltage on Open Circuit.* This is very slight and hardly amounts to more than 0.1 volt even after the cell has stood on the shelf for many months.

5. *Drop in Current When Standing on Open Circuit.* As the short-circuit current is considered a measure of the value of a cell by most dealers and by the public generally, so the drop in this characteristic is considered as measuring more or less accurately an actual deterioration in the value of the cell for service.

That this is not the case will be clearly seen from our remarks on the short-circuit current, particularly Table II, where it was shown that while the short circuit current of a lot of cells had dropped 84 per cent., the actual service capacity decreased only 19 per cent. thus showing that the two values were not directly dependent on one another.

This drop in short-circuit current, which is called "shelf life" in the trade, is, however, of great commercial importance to manufacturers in indicating quickly sources of trouble in dry cells so slight that their deleterious effects would show only after a considerable time. These sources of trouble might be poor proportions of the ingredients or imperfect mixing, impurities in the materials or the accidental introduction of foreign substances, and mechanical short-circuits between the zinc and the filling material.

By the "shelf-life" test as carried on by a large manufacturer two cells of each day's production in each standard grade and size made by the company are read and "put on the shelf." The cells are re-read after one, two, four and eight weeks and every eight weeks thereafter. The results are averaged by weeks and tabulated, so that the management can tell at a glance the quality, in respect to "shelf-life," of cells made on any week of its history. The original data is kept on file, so that the results on any single day's product can be determined if desired.

The "shelf-life" of dry cells of the standard sizes, namely, 2½ x 6, 3 x 7 and 3½ x 8 inches (6.25 x 15, 7.5 x 17.5 and 8.75 x 20 cm.) is usually considered as the age of the cell in months when the short-circuit current reaches 10 amperes. This value is chosen because it is about one-half the initial short-circuit current of the cell, and because it represents a value which is probably lower than the minimum point at which a dealer could dispose of a cell to the average consumer.

The best cells on the market have a "shelf-life" of 12 to 15 months, or even more in rare cases; 10 to 12 months is, however, more nearly the "shelf-life" obtained with the high-grade cells now on the market. Many manufacturers, whose product enjoys a good reputation, obtain only 8 to 10 months of "shelf-life," while we have often tested cells with "shelf-life" of only a month or two. This test is unfair to those makes of cells which read about

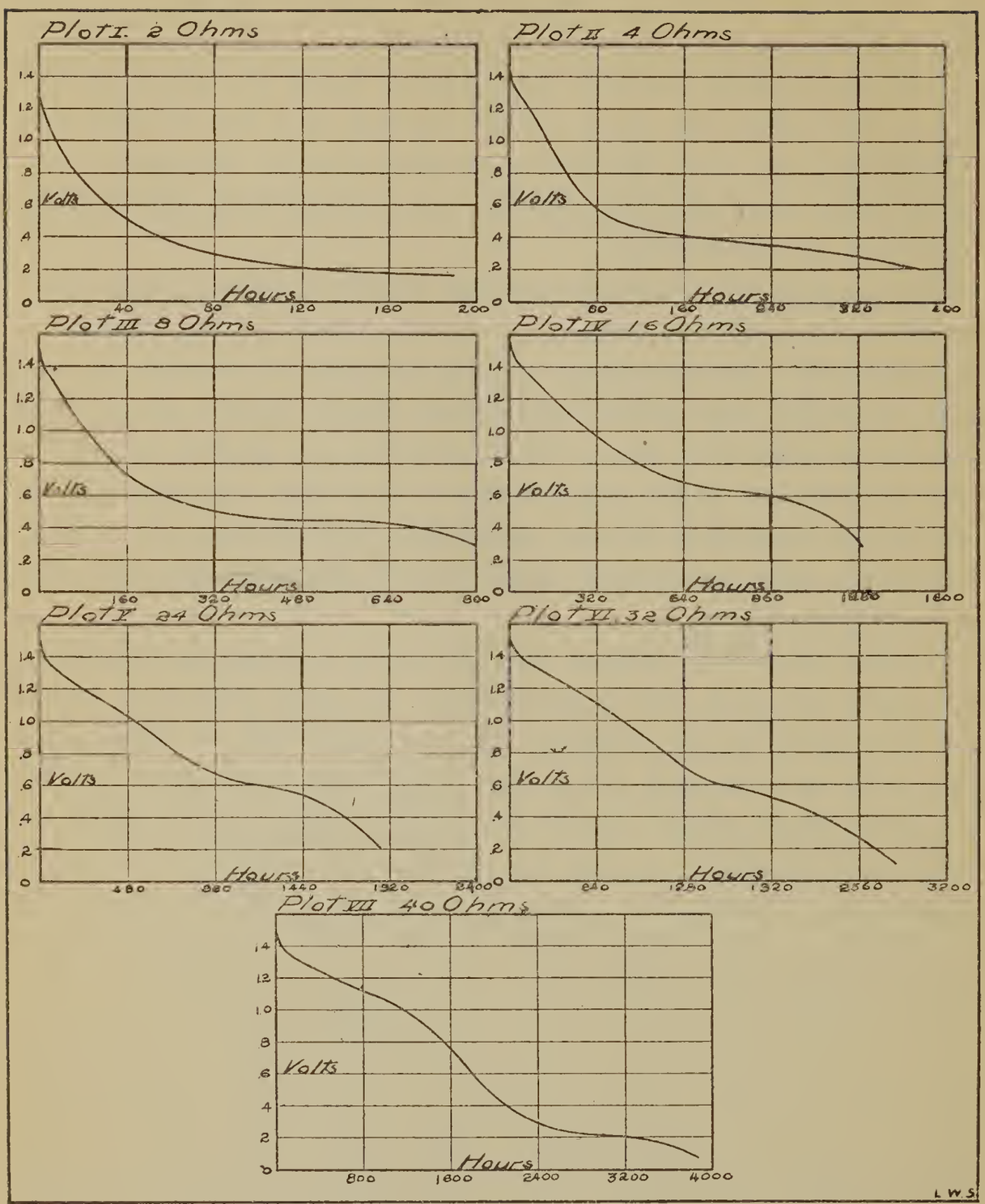


FIG. 1.
The Continuous Discharge of 2½ x 6 Inch Dry Cells.

10 amperes initially, but this occurs so rarely with supposedly high-grade cells that the individual instances are treated separately as they arise.

6. *Energy Output or Service Capacity.* It is, after all, the service obtainable from a dry cell that decides whether it is or is not satisfactory, and we will at this point present data on the service which may be expected from a dry cell when discharged

under various conditions. A standard brand of 2½ x 6 inch (6.25 x 15 cm.) cell was used in all of this work, and the results may be taken as applying in a qualitative manner to most of the high-grade cells now on the market.

Dry cells may be discharged either continuously or with periods of rest, or "recuperation," as it is called, between periods of service. In either case the working voltage, the current or the resistance of the external circuit may be kept constant, allowing the other two factors to vary as they will. A discharge through constant resistance represents most nearly the conditions in actual service, and we have therefore adopted this method in all of the work which is to follow on the service capacity of dry cells.

To show the effects of continuous service through different resistances, we present the curves shown in Plots 1 to 7. These plots are constructed from data obtained by discharging standard 2½ x 6-inch (6.25 x 15 cm.) dry cells under as nearly the same conditions as possible, continuously, through each of seven resistances, namely, 2, 4, 8, 16, 24, 32 and 40 ohms, and the plots show the decrease in working voltage as the time during each test increases. In each plot the abscissas represent the time during which the cell has been on test, and the ordinates show the working voltage after various times.

The ordinates remain the same throughout all of the tests, while the abscissas are changed so that the total length indicated on the plots increases in the same proportion as the resistances used. If, then, the working voltages decreased just in proportion to the resistances, these plots would contain curves of the same shape. That this is not the case is seen at a glance, and it will be noticed that there are two general changes brought about by increasing the resistance through which the cell is discharged. The first is that the top of the curve is broadened, or a much larger proportion of the total energy of the cell is delivered at higher voltages, and the second is that the lower end of the curve is made more abrupt, or the gain obtainable by operating to a lower working voltage is decreased.

The first effect is probably caused by there being a far more economical use of the depolarizer at low than at high drains, thus causing a comparatively slower drop in working voltage, while the second effect is doubtless caused by the actual exhaustion or

removal from action of the active ingredients of the cell. If the cell is opened after the rapid drop in working voltage shown in the tests at higher resistances has begun, the zinc will be found to be as thin as paper and perforated in many places, while the mix will be dry and hard, due to the formation of various double and basic salts during the discharge.

In Table III are given the hours of service to various working voltages and on various resistances, taken from these plots.

TABLE III.

Hours of Continuous Service of 2½ x 6 Inch (6.25 x 15 cm.) Dry Cells.

End Point in Volts	Resistances Used in Ohms						
	2	4	8	16	24	32	40
1.2	4.3	10	39	142	260	414	549
1.0	9.3	35	94	296	548	889	1148
0.8	16.5	51	143	414	751	1078	1550
0.6	28.2	76	225	954	1240	1600	1763
0.4	55	207	648	1197	1711	2280	2040
0.2	160	450	882	1318	1914	2626	3140

In order to show more clearly the points brought out in the above discussion, we have calculated from this same data the watt-hours of energy withdrawn from these cells when discharged through various resistances and to various working voltages. These values are given in Table IV, and the points noted above are brought out very clearly by it.

TABLE IV.

Watt Hours from 2½ x 6 Inch (6.25 x 15 cm.) Dry Cells Discharged Continuously.

End Point in Volts	Resistances Used in Ohms						
	2	4	8	16	24	32	40
1.2	3.7	4.3	8.1	15.2	18.8	21.7	23.8
1.0	6.7	13.0	16.5	26.9	33.4	39.8	42.0
0.8	9.7	16.3	21.5	32.8	40.3	44.6	50.6
0.6	12.5	19.4	26.6	48.9	49.5	52.7	53.2
0.4	15.4	27.3	39.1	52.6	54.3	58.2	54.8
0.2	19.8	32.6	41.5	53.3	55.2	59.3	57.1

Thus 15.2 watt-hours are withdrawn from a cell when it is discharged through 16 ohms to 1.2 volts, while to obtain 15.4 watt-hours from a cell discharged through 2 ohms, it must be run down until the working voltage is only 0.4.

Furthermore, if we consider 60 watt-hours as the maximum capacity of a six-inch cell when discharged under these circumstances, then when 50 watt-hours have been withdrawn it may be considered as about 5/6 discharged. A glance at the table will show that a cell short circuited through 40 ohms is 5/6 discharged when the working voltage reaches 0.8, while if the cell is discharged through 16 ohms, 0.4 volts must be reached before the same amount of energy has been taken from it.

Such calculations as these are interesting from a theoretical point of view, but practically this oft-repeated question as to the ampere-hours or watt-hours to be obtained from a cell is of very little moment. What the user wants to know is not the amount of energy which a cell is capable of delivering, but the actual hours of service that he can obtain with a definite piece of apparatus connected under definite conditions to a definite battery.

Turning now from continuous to intermittent service, we approach much more nearly to the conditions found in actual practice, and data will be presented showing the changes in service capacity which accompany a change from a continuous to an intermittent discharge.

The tests shown on Plots 8, 9, and 10 were carried out at room temperature under as nearly similar conditions as possible. Each curve in Plot 8 represents three cells in series discharged through 5 ohms resistance. Curve A shows the drop in working voltage when the cells were discharged continuously. In the test represented by curve B, the three cells were discharged five minutes in each hour, and the curve is a line drawn through the working voltage at the end of these five-minute periods. In the plot, the 55-minute periods of recuperation are omitted, so that we have represented the minimum working voltages during the actual time that the cells were short circuited through the 5-ohm coil. Curve C represents a similar test in which, however, the three cells were short circuited through 5 ohms for five minutes per hour, only eight hours per day, and six, or in some cases five, days per week.

The curve is a line drawn through the working voltage at the end of the last contact in each day's service. The three curves in Plot 9 are similar to the above except that the cells were short circuited through 10 ohms instead of 5, and in Plot 10, 20 ohms was the resistance used on the three tests. We have thus three rates of drawing energy from the cells at each resistance, and tests through three resistances at each of these rates.

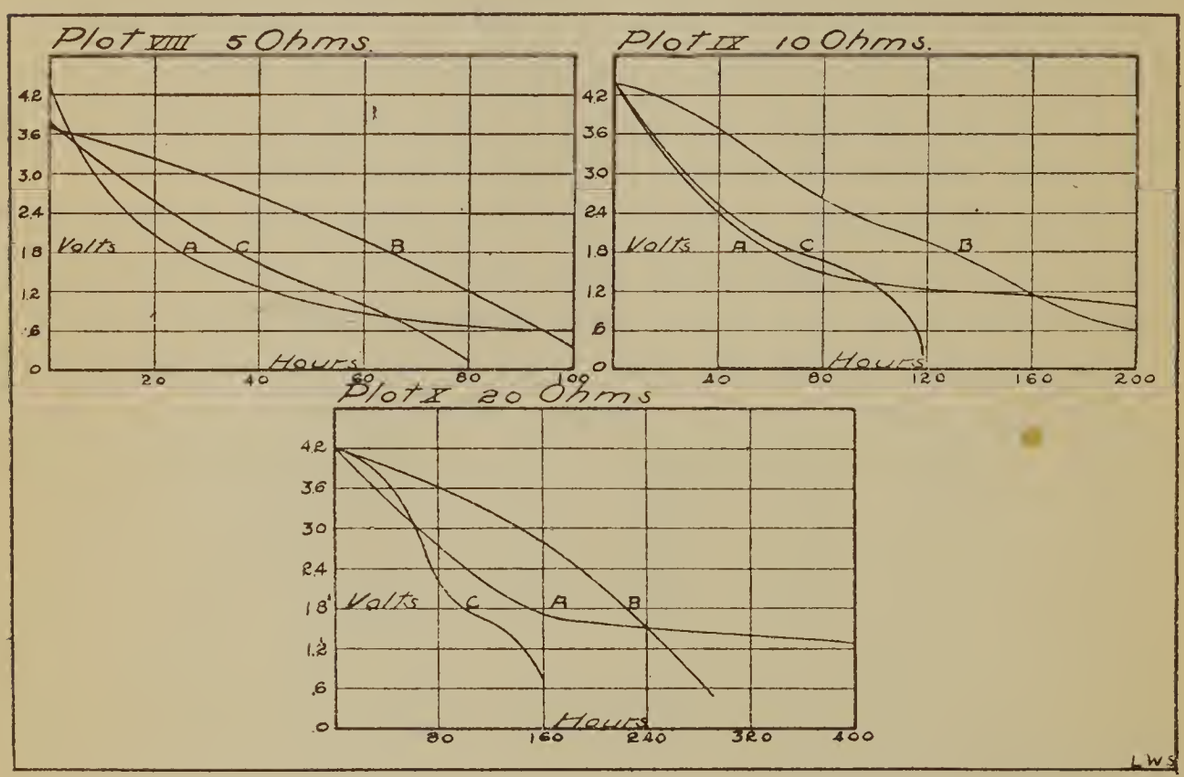


FIG. 2.
The Intermittent Discharge of 2½ x 6 Inch Dry Cells.

An examination of these curves leads to the following conclusions:

1. During the early stages of the test, longer actual service is obtained to a given working voltage when the battery is discharged intermittently than when it is discharged continuously.

2. During the later stages of the test, the intermittent curve crosses the continuous and it becomes less efficient to operate the battery at intervals than continuously.

3. This effect occurs earlier in the test, that is at a higher working voltage, as the resistance through which the battery is discharged increases.

The effect noted under 1 is doubtless chiefly due to the extra

time for depolarization that is given to the battery on the intermittent tests, and it is probably of the same nature as the broadening of the top of the curves noted in continuous tests as the resistances used were increased.

The effect noted under 2 and 3 may be due to a deterioration of the cells while on service and while standing on open circuit during periods of rest. This becomes more probable when we consider that curve C is in each case lower than curve B, although they differ only in that the cells represented by C were on test less than one-third as long per week as those represented by B.

In concluding the discussion of these tests it must not be forgotten that the curves represent only the time during which the batteries were short circuited. If the actual length of the test were plotted, B would be extended 12 times and C nearly 40 times as far as given, while A would remain unchanged.

The data given above may serve as a basis for the determination of the size and arrangement of a battery for the most economical service with any particular type of apparatus. In thus selecting a battery two factors are to be considered:

1. The number of cells which should be connected in the series direction.

2. The number of cells which should be connected in the parallel direction.

There is usually but little choice on the first point, for most electrical apparatus is designed to operate on a certain definite voltage, which cannot be changed except between rather narrow limits. In general, to increase the number of cells in series in a battery increases the average drain and lowers the limit to which each separate cell can be discharged. Where this low limit is very near the initial working voltage of the cells, it may sometimes be advantageous to increase the number in series, but in general this is not the case, and it will often give rise to serious difficulties if apparatus is operated on a higher working voltage than that for which is was designed.

To increase the number of cells in parallel in a battery decreases the average drain per cell, and from what has preceded we can say at once that as the service becomes heavier, and the end or cut-off voltage higher, it becomes of greater advantage to

increase the size of the battery in this direction. Suppose, for example, that a certain piece of apparatus has a resistance of 2 ohms, and is operated by a single cell continuously to a working voltage of 0.8, then a glance at Table II shows that 16.5 hours of service were obtained on this test under the conditions given. If, now, four cells are connected in parallel through this same apparatus the drain becomes one-fourth as great as before, and each cell is discharged as though it were connected through 8 ohms resistance. The same table shows that 143 hours of continuous service were obtained, or an increase from 16.5 hours per cell to 35.7 hours per cell in the battery used. This gain in economy is seen to persist until the average drain becomes very low, but for very light or long continued service, such as is shown in the intermittent tests on Plots 9 and 10, it is more than offset by the deterioration caused by local action on standing. We find, in fact, that with heavy service, such as ignition, it is of great advantage to use batteries containing more than one set of cells in multiple, while with light service, such as is usual on telephones, it is a positive disadvantage to do this.

The effect of temperature on the characteristics of dry cells is a subject to which too little attention has been given, for it is not generally realized how pronounced this effect may become under certain conditions. Before proceeding with the subject of dry-cell testing, we will very briefly note the effect of temperature on the principal characteristics in the order in which they have been treated.

1. *The effect of temperature on electromotive force* in dry cells is very slight, amounting to only a few hundredths of a volt at all ordinary ranges. The voltage returns to normal with the temperature.

2. *The effect of temperature on the short circuit current* is somewhat more pronounced. Between 10 and 80 degrees centigrade the amperage of a dry cell is raised on an average about 1 ampere for every 10 degrees' rise in the temperature. This value varies considerably with different cells, and is somewhat greater at the lower (colder) end of the scale and less at the higher end. At extremely low temperatures the effect becomes very pronounced, and it is often noted that cells received in

extremely cold weather read only one or two amperes. On bringing them to room temperature, however, the short-circuit current becomes normal and the cell is found to be none the worse for its freezing.

3. *The rate of drop in short-circuit current* is decreased by lowering the temperature at which dry cells are stored. Table V shows results obtained with standard cells kept at approximately 0°, 25°, 50° and 75° Centigrade, respectively. These cells read initially about 20 amperes. The table shows their short-circuit currents at 25° Centigrade after being stored for five months at the temperatures given. This indicates why it is always recommended by dry cell manufacturers that dealers and users store their cells in a cool place.

TABLE V.

The effect of Temperature on the Shelf-life of 2½ x 6 Inch (6.25 x 15 cm.) Dry Cells.

Temperature at which cells were stored.	Short circuit current at 25° C., after 5 months
0° C	18.1
25°	17.4
50°	0.5
75°	0.4

4. *The service capacity of dry cells* may be either increased or decreased by raising the temperature according to the conditions under which the cells are tested. In general, more service of a severe nature will be obtained if the cells be moderately warmed, while with very light service it is advantageous to keep the cells cool. It is dangerous, under any circumstances, to use dry cells at temperatures much above 50° Centigrade.

The magnitude of this temperature influence is shown in Table VI, which shows the hours of service obtained with cells discharged at approximately 0°, 25°, 50° and 75° Centigrade, through 2 and 32 ohms' resistance, to a working voltage of 0.5. It will be noted that at the high drain the maximum service was obtained at 50 degrees, while on the light service test the best results were obtained at 0 degrees.

TABLE VI.

The Effect of Temperature on the Service Capacity of 2½ x 6 Inch (6.25 x 15 cm.) Dry Cells.

Temperature at which cells were tested.	Resistances through which cells were discharged.	
	2 ohms.	32 ohms.
0° C	40 hrs.	1800 hrs.
25°	60	1550
50°	70	1250
75°	65	1390

THE USE AND TESTING OF DRY CELLS.

The first dry-cell test, and the one which, unfortunately, still very largely prevails as a method of determining their value, consisted in a measurement of the short-circuit current. The previous discussion of this subject will indicate, without further comment, the shortcomings of this method of test.

Following the short-circuit current test came the continuous resistance test, and it was a long step in advance when it began to be used. In order to obtain results quickly the cells were at first discharged continuously through 2 ohms' resistance until the working voltage reached a certain value. It was soon seen, however, that such results had little practical value, because they could not be translated into the results which might be expected on actual service. It became the custom, therefore, to discharge cells for test through a resistance as near as possible to that used in practice. This led to an examination of the conditions obtaining in actual service, and it was soon seen that it was only by devising a test which would as nearly as practicable duplicate the conditions under which the cells were to be used, that data for their positive valuation for a given service could be obtained.

After this point had been reached the advance was rapid, and we will briefly review the conditions of service and the tests most applicable in the two kinds of use to which dry cells are most commonly put.

1. *Telephone Service.* Dry cells used in telephones are connected two or three in series, and discharged through a resistance of about 12 to 16 ohms, the discharge lasting as long as the receiver is off the hook. To represent as nearly as possible average telephone service, a dry-cell telephone test would discharge

two or three cells in series through about 15 ohms for as many periods each day as there are calls on the average telephone, each period being of the length of an average telephone conversation, and the cut-off point being taken as the lowest working voltage that will give satisfactory service.

The large telephone companies and the dry cell manufacturers have worked along these lines for some years, and a number of tests have been developed which fulfil to a greater or less extent the conditions outlined above. Among the early tests were some which included the attachment of the testing apparatus to the circuits of regular commercial phones, so that the results of the test necessarily varied with the amount of use given the phones, and therefore could not be duplicated; but these uncertain and unscientific methods are now for the most part abandoned, and most large manufacturers and consumers make telephone tests by means of clock-operated relays which make contacts of definite length at definite periods throughout the test.

One of the largest telephone companies has developed the following test, and has constructed a very complete and elaborate apparatus for carrying it out. Three cells are discharged in series through 20 ohms resistance for four minutes per hour and 10 consecutive hours per day, six days in the week. On the seventh day there are five four-minute contacts at two-hour intervals, lasting in all for 10 hours. About once a week, at the last of the 10 contacts for the day, three readings are taken, as follows:

1. Open circuit electromotive force just before contact.
2. Closed circuit voltage at the beginning of the contact.
3. Closed circuit voltage just before the end of the contact.

The test is continued until the third reading reaches 2.8 volts for the three cells in series. This usually takes about six months under the conditions given and with cells of good quality.

This test has the advantage of being the standard for a very large consumer of telephone cells, but its labors under the great disadvantage of being cumbersome and far more complicated than is necessary to approximate telephone practice as nearly as is advantageous in a test of this sort.

One of the largest dry-cell manufacturers uses the following

much simpler test for telephone service: Three cells in series are discharged through 20 ohms resistance for two minutes per hour, 24 hours per day, and seven days per week. About once a week the working voltage is taken just before the end of a contact, and the test is considered as finished when this value reaches 2.8 volts for the three cells in series. This test puts the cells on discharge for 336 minutes per week, as against the telephone company's 260 minutes. It is far easier to operate a test of this sort, and it is, we believe, very unlikely that there is any gain to be derived from introducing the unequal periods of service used by the telephone company in its standard test.

It may be argued that a single cell discharged through one-third of the resistance in a similar manner would give the same results more simply and economically. Three cells are used in series on these tests, not only because it is according to actual practice, but also because a result is obtained which represents more nearly the average value of the cells used and which is not so much influenced by individual variations in quality. These two considerations, we believe, far overbalance the increased cost of the test and make it of importance that the practice of testing a complete battery as a unit should be continued.

Many makers and users of dry cells employ what is known as a short telephone test in which the battery is discharged usually in the same manner as for the long test, but through 5 ohms resistance instead of 20 ohms. This test departs so far from actual practice that its results can be taken only as a rough indication of the value of the cells tested on this sort of service, and it is questionable whether a continuous test is not equally satisfactory, and it is certainly far simpler. For instance, instead of testing three cells in series through 5 ohms for two minutes per hour, a single cell might be discharged continuously through 50 ohms resistance to the same cut-off point. This would give an average drain per day similar to that obtained on the intermittent test, and the results could be obtained without the necessity of using the rather complicated make-and-break device that is employed in the longer test. We do not claim that the results of these tests will be the same, but either will probably serve to eliminate those cells which are entirely unfit for use in telephone service.

2. *Ignition Service.* Dry cells for automobile and gas engine ignition are usually sold by small dealers and consumed by individuals, with the result that the manufacturers are almost the only ones who have seriously studied the problem of developing a suitable test for cells designed for this service.

As the demands of ignition service on the dry cell are radically different from those of telephone service, and by no means as well understood, we will take time at this point to indicate briefly those points which are of particular importance in the consideration of the subject.

Of the various types of ignition used in gasoline engines we will consider here only the most usual, in which the battery current passes through the primary of an induction coil at the right moment in the engine's cycle, and by means of a vibrator is made to rise and fall very rapidly, thus producing pulsations of very high voltage in the secondary, and a series of sparks at the spark plug which ignites the explosive mixture in the engine cylinder.

If the current drawn from the ignition battery were traced from moment to moment by means of an oscillograph, or otherwise, it would be found to have approximately the form shown in Plot 11. In this plot the abscissas represent the time in seconds and the ordinates the current flowing in amperes. The whole plot shows the battery drain during two revolutions or one complete cycle of a four-cylinder automobile engine. The spaces A, B, C, and D show the periods when the timer or make-and-break device, which is geared to the engine shaft, is on contact. The short impulses 1, 2, 3 and 4 show the rushes of current through the primary at each movement of the vibrator on the induction coil. If now a Weston milli-ammeter be placed in the circuit it will be found that these rushes or impulses of current are so rapid that they will be damped out or averaged by the instrument, and we will have a steady current indicated by the needle and shown at *M* in the plot, which current, it has been shown by comparison with a voltameter, is very nearly the average current flowing in the circuit. The ignition battery, then, in order to give satisfactory service, must be capable of giving not only the average current *M*, but it must be able to supply the momentary impulses 1, 2, 3, 4, through the primary of the coil.

The primary of the average induction coil has a resistance of about 0.5 ohm, and if the circuit through the coil were to be closed indefinitely the current would rise to from 12 to 16 amperes, depending on the voltage of the battery used. The action of the vibrator is so rapid, however, that the current does not have time to build up to its maximum value, and the actual initial impulse rises to only three or four amperes, as shown in the plot. By careful and repeated observations with an actual gasoline engine we have, however, been able to determine the relation between these two values, and by measuring the current which will flow through a half-ohm coil when it is used to short circuit a battery which will barely ignite an engine satisfactorily,

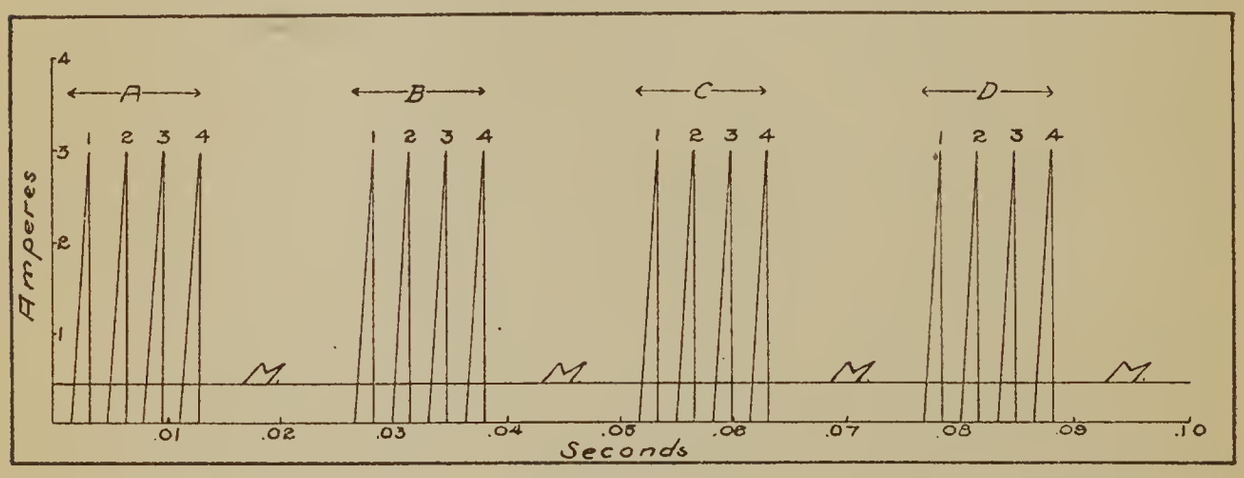


FIG. 3.
Diagram of the Current in an Ignition Circuit.

we have determined that a battery, in order to give satisfactory ignition service, must be capable of giving from two to four amperes when short circuited through a half-ohm coil for a few seconds. This would, of course, correspond to a considerably lower operating or momentary impulse, such as is shown in Plot 11, but it is a value based on repeated experiment under the most various conditions, and it is, we believe, quite closely representative of average ignition service and at the same time easy to obtain. Ignition apparatus, it must be remembered, is not of a nearly standard type, as is telephone apparatus, and therefore all figures given here are liable to great fluctuations in individual cases. We have, however, examined most of the more commonly used brands of ignition devices, and we find that the following represents as nearly as can be determined the average

conditions which will be found to obtain in the large majority of dry cell ignition apparatus now on the market.

1. The battery will consist of four, five or six cells in series, and usually of the latter number (five cells in series will, in almost every case, give as satisfactory service as six).

2. The battery must be capable of giving a current of four amperes when short circuited for a few seconds through a half-ampere coil. Many of the better ignition devices require an impulse of only two amperes, but four amperes has been taken here as being nearer the average, and more conservative.

With the above statements in mind, we can now proceed to the discussion of the testing of dry cells designed for ignition. Any other general points which must be brought out can be treated as they arise.

The earliest ignition tests were made by operating an actual gas engine under as nearly standard conditions as possible for about eight hours per day, considering the test finished when the battery failed to give satisfactory service. With this test, as with the older telephone tests, so many uncontrolled factors were introduced that tests made at different times could not be satisfactorily compared, and the method was developed by simply discharging the battery through a spark coil continuously for eight hours per day until sparks were no longer obtained at a spark plug placed across the secondary of the coil. Finally, a rotating make-and-break device similar to a gas engine timer or commutator was introduced into the circuit, and in this way the average drain was made as nearly as possible like that of actual ignition service.

The value of these tests made with actual induction coils was, however, much diminished by the fact that no coil could be found which would keep in permanent adjustment. Even when a coil was accurately adjusted to a given current consumption in the morning, by evening of the same day it would be found seriously out of adjustment, and this, combined with the fact that the appearance of a spark at the spark plug in air is no indication that the proper conditions obtain for ignition in a gas engine cylinder, led to the abandonment of tests through actual induction coils, and the substitution of resistances for them.

From this point the development of the ignition test proceeded towards the conditions indicated by the preceding outline of ignition service, and as a result of such development the following may be given as a standard test of dry cells designed for ignition: Six cells in series are discharged through 16 ohms resistance for two hours per day, one hour in the morning and one hour in the afternoon. About twice a week the cells are short circuited through a half-ohm coil for a few seconds and the current flowing is noted. When this current flowing, or impulse, reaches four amperes, the battery is removed from test, and the life of the battery is reported as the hours of service given under the above conditions to four amperes impulse through a half-ohm coil. A modern dry cell of good quality will give 30 hours of service on this test at ordinary room temperature of, say, 22 to 24° Centigrade.

This is the only scientific ignition test that we know of which is based on the actual conditions of ignition service, and which therefore can be depended on to give results corresponding closely to what may be obtained in actual automobile service. The results of the test are considered to apply most closely to four-cylinder combustion engines, and in order to convert them to miles of service, it is customary to multiply the hours of service by 20, thus assuming an average speed of 20 miles per hour.

The above are the only classes of service for which definite tests have been worked out and adopted by large manufacturers. We will, however, close this paper by noting a few of the other uses of the dry cell, with suggestions for testing:

1. *Bells and gongs* are usually operated by means of dry cells. In most cases the service is very light, indeed, and a "shelf-life" test will indicate the cell most suitable for the purpose.

2. *Miniature electric lights* in motor boats, automobiles, houses, camps, etc., are very often operated by a battery of dry cells. It is usual in such service to employ six-volt, 2.5-watt tungsten lamps and operate them by means of a battery of five dry cells in series, a series being added to the battery in the parallel direction for each lamp in the installation. A single series of cells with a single light will be found to give about 50 hours of service if used only three or four hours each day. A

satisfactory test for this sort of service is to discharge five cells in series through 16 ohms resistance for two hours a day until the working voltage reaches 4.5.

3. *Flash-lights* are small 3.5-volt tungsten lamps, mounted in a pocket case with a battery of three very small dry cells connected in series. The following test may be used for three-cell flash-light batteries. A complete battery is discharged through 12 ohms resistance for five minutes per day until the working voltage at the end of the five-minute period drops to 3.0.

4. *Telephone bell ringers* are operated by dry cells in many small exchanges, and for this service a battery of 60 cells in series is employed. The current drain is very low, averaging only about 0.02 amperes, and no test, so far as we know, is carried out for this service.

5. *Earphones,* to improve the hearing of the deaf, are now made in large numbers and are operated by dry batteries similar to the flash-light batteries, but containing only two cells in series. They are given the same test as is used for flash-lights, except that 8 ohms resistance is used instead of 12.

6. *Medical induction coils* are widely used throughout the country, and they are almost universally operated by dry cells. No special test has been devised for this sort of work.

7. *Miscellaneous* uses for the dry cell are for the operation of automobile horns, sewing-machine motors, small desk fans, toys of all sorts, electric massage vibrators, annunciators, cigar lighters and various kinds of signals, etc. In the aggregate these miscellaneous uses consume enormous numbers of cells every year, but they are so numerous, and there are such various conditions prevailing in each kind of service, that no attempt has been made to develop tests covering them.

In conclusion, we wish to point out again what will probably have been evident on reading the body of this paper, namely, that there is no test which the small consumer can apply to a dry cell or battery, which is inexpensive and which will indicate rapidly

and simply the value of the cell. He must do in this as in so many other cases—buy from reputable dealers the brands that he knows are made by reliable and progressive manufacturers.

Research Laboratory,
National Carbon Co.,
April, 1910.

DISCUSSION.

MR. CARL HERING: I am exceedingly interested in this paper, and am glad to see that someone has started to make the tests which are so much needed. What is required from the dry cell is service, and this may be obtained from a battery of many cells running each at a low discharge, or from a few cells working hard and giving the same output. What we want to know is which one of these arrangements is the cheapest to use. I have tried to get this information in many places without success; can Mr. Ordway tell us?

MR. D. L. ORDWAY: As indicated in the body of the paper, it may be said of all except the lightest kinds of service, that the lower the drain per cell, and the lower the cut off voltage, the greater will be the economy in the use of a given dry cell. For all ordinary or severe services it will be of advantage to the user to decrease the average drain per cell by increasing the number of cells in multiple.

A paper presented at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 7, 1910, President L. H. Baekeland in the Chair.

ELECTROCHEMICAL POTENTIALS AND ELECTRICAL CONDUCTIVITY OF ALUMINUM-CALCIUM ALLOYS.

By James M. Breckenridge.

Modern research has shown that combinations of metals may take the form of simple mixtures, solid solutions or chemical compounds. In the two former, the physical and chemical properties of the alloy formed must result from a blending of the characteristics of the original metals. With the compounds, on the other hand, the union of these metals in atomic proportions may result in a substance with properties entirely at variance with those of the original constituents.

Since the alloys of the calcium-aluminum series presented physical and chemical properties which were different from the original metals (Trans. A. E. S., Vols. 13 and 15) it was thought that this marked change of properties might be due to the presence of one or more chemical compounds, and for this reason a study of the constitution of the alloys of this series was undertaken.

Several methods are adapted to the study of the nature and constitution of alloys. Roberts-Austen[1] has classified them under the two following heads:

(1) The chemical grouping of the metals in a solid alloy.

(2) The separation of the constituents during solidification.

The first group includes the following special methods:

(a) The specific gravity of alloys.

(b) The electrical resistance of alloys.

(c) The diffusion of metals in alloys.

(d) Electrolytic conduction.

(e) The heat of combination of metals to form alloys.

(f) The electromotive force of alloys.

(g) Microscopic examination of alloys.

[1] Law: Alloys, p. 39.

The second group deals with those methods involving a study of the separation of the constituents of an alloy on solidification, and includes:

(a) Measurement of the fall of temperature during solidification by means of a pyrometer.

(b) Mechanical separation of constituents of an alloy by heating to definite temperatures and pressing out liquid portions.

In this particular investigation an attempt was made to locate the compounds formed by the following methods:

(1) Measurements of single potentials in non-aqueous solutions.

(2) Measurement of electrical conductivity.

The measurement of single potential was introduced by Laurie[2] and has given valuable results. Puschin[3] has employed this method with a number of alloys, and finds that the compounds located in this way agree exactly with the compounds located by means of cooling curves. Laurie and Puschin have found that a sharp depression in a single potential curve indicates the presence of a compound at that point.

These conclusions are in agreement with Toutourine[4], whose work goes to prove that:

(a) The single potential is a function of the composition of an alloy.

(b) Depressions in curve indicate compounds.

(c) The initial and terminal point of each line is determined by the single potential of the phases forming the series.

(d) Solid solutions do not affect the series.

The study of the elecrical conductivity of alloys began with the work of Matthiessen in 1860. He showed that the conductivity curve was similar to the cooling curve of the same alloy. LeChatelier[5] and Rayleigh[6] have shown independently that the temperature factor for the conductivity of alloys is entirely independent of the temperature factor of pure metals. Kurnakow

[2] Chem. Soc. Journal, **53**, 105 (1888).
[3] Zeit. für anorg. Chemie., **56**, 1.
[4] Soc. Chimique-France (1908).
[5] Compt. Rendus, III, 454; **119**, 126 (1907).
[6] Nature, **54**, 154.

and Zemczuznyj[7] have shown that solid solutions lower the conductivity, and that the curve formed by such solutions is continuous and has a minimum value. Guertler[8] has shown that it is possible to establish the exact relationship between the conductivity curve and the compounds formed in a series of alloys. He shows that Liebenow's[9] conclusions, concerning the location of compounds by means of sharp, upward projections in the conductivity curve, are not entirely necessary, for, in many cases, a compound occurs where there is but slight elevation, or perhaps a slight depression. Guertler concludes that the absence of an elevation does not necessarily indicate the absence of a compound, but the presence of such an elevation is absolute evidence of the presence of a compound.

The preparation of the alloys for single potential and conductivity measurements in this investigation was as follows: The calcium was added to the fused metal with which it was to be alloyed as soon as the latter was liquid. This allowed the two metals to be heated in contact, so that the resulting alloy formed at the lowest possible temperature. After the required amount of calcium had been added, the molten metal was poured as quickly as possible into an iron mould which had been heated to a temperature just below the freezing point of the alloy. This produced a chilling effect sufficiently great to prevent the segregation of the metals forming the alloy. The amount of metal poured in each case was sufficient to fill the entire mould, as well as the entrance chamber above the mould. This enabled the alloy to pass from the temperature of the molten metal to a point considerably below its solidification temperature in the absence of air.

During the progress of these experiments it was found advantageous to hold the temperature of the alloy constant for some time after pouring. The mould was then cooled slowly.

Fused calcium chloride was used as a covering for these alloys during the process of melting.

Several difficulties were encountered in the attempt to measure the single potential of calcium alloys. It was necessary to use a non-aqueous electrolyte on account of the calcium content of

[7] Ber. St. Petersb. Polyt. Inst., 6, 559.
[8] Zeit. für anorg. Chemie., **52**, 413.
[9] Zeit. für anorg. Chemie., **60**, 209.

these alloys. After considerable experimental work with various non-aqueous electrolytes, a solution of calcium chloride in ethyl alcohol was selected for this work.

The ethyl alcohol was allowed to stand over freshly ignited lime for five days. This mixture was shaken from time to time. The alcohol was distilled from the lime in a moisture-free apparatus. After distillation the alcohol was treated with a fresh supply of lime and allowed to stand for some time. This process was repeated twice, after which the alcohol was treated with anhydrous copper sulphate and allowed to stand for five days, during which time the mixture was shaken from time to time. The alcohol was distilled off, using the same precautions as before. After two treatments with anhydrous copper sulphate the material showed no evidence of the presence of water when placed upon anhydrous sulphate, even after an interval of ten days.

In each distillation the first 25 c.c. of the distillate were rejected.

A N/12 solution of calcium chloride was prepared. Kahlbaum's anhydrous calcium chloride was used. This had been heated for eighteen hours at 120° C. A fine white precipitate remained in suspension in this solution. This stock solution was kept in a glass stoppered bottle.

Considerable difficulty was encountered in an attempt to prevent the diffusion of the aqueous solution of the normal calomel electrode and the non-aqueous solution in which the single potential of the alloy was to be measured. The ordinary connection of the normal calomel electrode was worthless. A modification of this worked very well.

Pieces of glass tubing were heated and pulled so as to form a narrow constriction in the tube. These were packed on either side with finely macerated filter paper moistened with water. The constriction served to hold the plugs in place. These tubes were dried in an oven and the macerated filter paper was pressed firmly together. The filter paper plugs were ¾-inch in length. These glass tubes containing the plugs were sealed to the tubes leading to the normal calomel electrode and to the half-cells in which the single potentials of the alloys were to be measured. These

tubes served as the connections with the intermediate vessel. That the diffusion was reduced to a minimum was shown by the fact that when the eletrolyte was placed in the half-cell and the alloy placed in contact with the solution, it was necessary to add more electrolyte in order to make a reading only after the lapse of several hours.

The half cells were dried for several hours at 115° C. and allowed to cool in a desiccator containing sticks of sodium hydroxide. The electrolyte was poured in and the alloy placed in contact with the solution. The half cell was stoppered with a rubber stopper. Rubber stoppers were used in all cases. The half cells were kept in desiccators when not being actually measured.

The alloy whose single potential was to be measured was thoroughly cleaned and its surface polished, so as to remove the scratches visible to the naked eye. Electrical contact with the alloy was made by means of a fine copper wire. The junction of the wire and the alloy and that portion of the wire within the half cell were covered with a heavy layer of wax to prevent the formation of a couple in case the electrolyte should come in contact with the wire and the alloy.

The intermediate vessel was closed with a two-hole rubber stopper, so that the arms from the normal calomel electrode and the half cell could be inserted without loss of time when a single potential measurement was to be made. When not in use this vessel was kept closely stoppered so as to prevent the entrance of moisture. An alcoholic solution of calcium chloride was used as the intermediate solution between the calomel electrode and the half-cell. After each measurement the contents of the intermediate vessel were thrown away and a new supply used for the next measurement. This arrangement reduced the amount of moisture present to a minimum.

The single potentials were measured by means of a direct-reading Leeds and Northrup potentiometer. This enabled individual readings to be made in less than one minute. A D'Arsonval galvanometer was used as a zero instrument.

The electromotive force varied considerably at first. Measurements were made every thirty minutes at the beginning of the

work. As the amount of variation decreased the interval between the readings increased. In some cases forty-eight hours were required to obtain constant readings.

The method employed in making the conductivity measurements was as follows: Each bar of the individual members of the series was supported upon two knife edges which were connected to a direct-reading Leeds and Northrup potentiometer. In this way the same length of bar was measured in each case. Several measurements of the diameter of each bar were made and the average used in the computations. As there was some variation in the final conductivity values of the bars of each of the different percentages, the average value was taken. A current of from ten to fifty amperes was passed through the bars and the ammeter and potentiometer readings were taken simultaneously. Contact with the bars was made by means of two heavy brass springs which held the bars firmly upon the knife edges.

All measurements were made at room temperatures.

Table I gives data obtained in the measurement of the single potentials.

TABLE I.

E. M F.	Time in Hours	Percent Calcium	Single Potential
.6550	24	Al.	0.0950
.7203	36	3.07	.1603
.7300	48	6.0	.1700
.9108	24	11.5	.3508
.9300	28	12.7	.3700
.9480	22	19.4	.3880
1.0290	4	23.9	.4690
1.0250	8	25.0	.4650
1.0320	4	26.9	.4720
1.0450	9	27.0	.4850
1.0270	8	28.5	.4670
1.0400	7	31.2	.4800
1.0410	4	32.8	.4810
1.4720	10	34.3	.9120
1.4700	12	37.7	.9100
1.4810	16	50.3	.9210
1.5280	20	60.0	.9280
1.5220	21	70.5	.9620
1.5410	12	75.0	.9810
1.5400	21	78.8	.9800
1.6240	15	80.2	1.0640

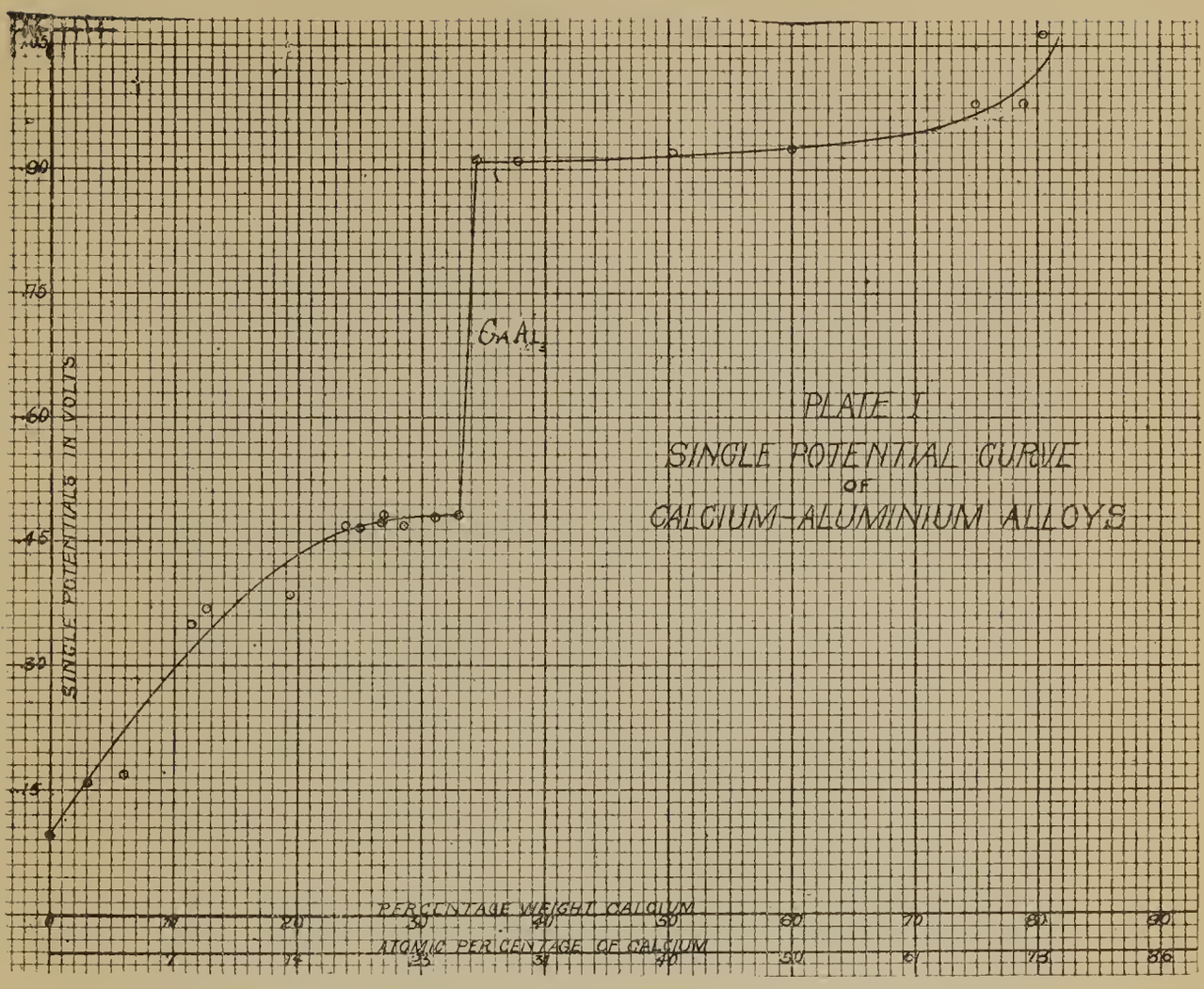


FIG. 1.

Table II gives data obtained in the measurement of electrical conductivity.

TABLE II.

Percent Calcium	Diameter in cm.	Amperes	Millivolts	Microhms per cm.	Specific Conductivity
3.07	0.819	37.50	0.8	15.8	63291
6.00	.822	32.75	0.9	20.2	49505
9.1	.812	34.75	1.25	27.1	36900
12.5	.822	28.75	1.50	38.4	26042
19.4	.829	29.25	2.0	49.5	20202
23.9	.835	32.25	4.5	99.5	10050
25.0	.836	28.25	4.5	113.4	8848
28.5	.842	10.75	1.8	117.0	8547
31.3	.855	11.50	2.0	118.0	8474
32.8	.887	26.00	4.6	112.0	8928
37.7	.860	19.00	3.1	110.0	9091
50.0	.862	20.00	4.2	141.0	7093
60.0	.847	28.50	7.0	171.0	5848
75.0	.850	6.25	1.7	189.0	5298
78.8	.837	9.5	1.5	112.0	8928

The length of bar measured in each case was 2.56 centimeters.

The break in the single potential and electrical conductivity of the calcium-aluminum series occurs between 32 and 34 percent

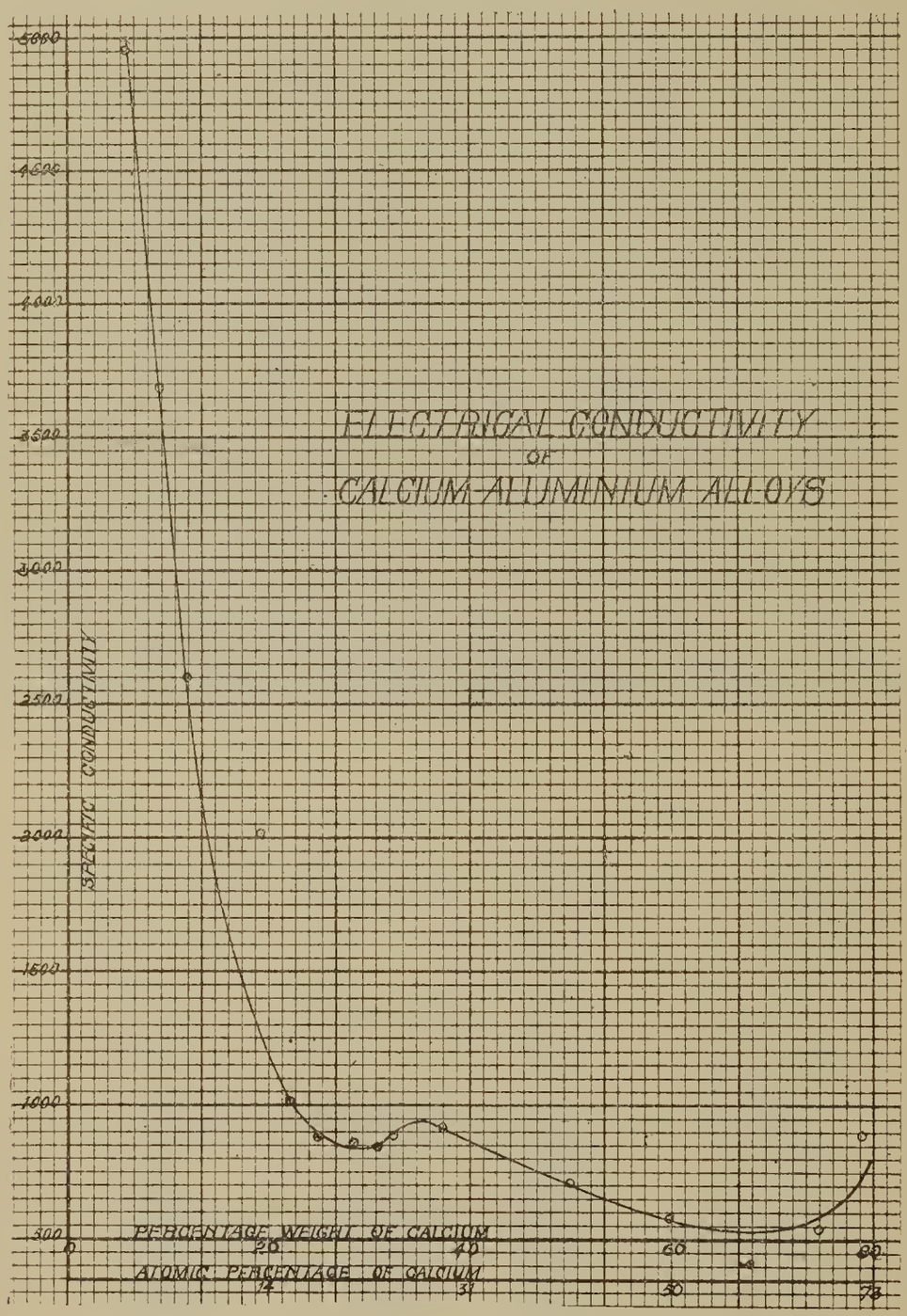


FIG. 2.

calcium. This corresponds to the formula Al_3Ca, and is in agreement with the results obtained by Donski[10] in the study of the cooling curves for this particular series.

[10] Zeit. für anorg. Chemie., **57**, 201.

CONCLUSIONS.

I. Aluminum and calcium form the compound Al_3Ca.

II. The study of the single potentials and the electrical conductivity is a valuable aid in determining the nature and constitution of a series of alloys.

In conclusion, the author wishes to express his gratitude for the timely suggestions and advice received from Professor C. F. Burgess and Professor O. P. Watts during the progress of this investigation.

Department of Electrochemistry,
University of Wisconsin.

A paper presented at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 7, 1910, President L. H. Baekeland in the Chair.

ON THE ELECTROLYTIC REDUCTION OF NITRIC ACID—III.

By Harrison E. Patten and W. J. McCaughey.*

Section XIII.[1]

The electrolytic reduction of hydroxylamine in sulphuric acid solution, at a copper cathode with copper sulphate present; oxidation of hydroxylamine at a platinum anode.

An aqueous solution containing 68.600 grams H_2SO_4, 13,333 grams $CuSO_4.5H_2O$, and 10.160 grams $NH_2OH.HCl$ made up to 3,400 c.c. was electrolyzed in the cell shown in Fig. 10,[1] using a copper cathode 100 sq. cm. in area and a polished platinum anode 56.6 sq. cm. in area. The hydroxylamine hydrochloride used was found in Fehling's solution to contain 89.6 percent of the theoretical NH_2OH, consequently 11.340 grams were weighed out to secure the 10.160 grams required to give the solution a hydroxylamine-nitrogen content equivalent to that of the nitrate solution reduced in Section XII. No residue was left when the solid hydroxylamine hydrochloride was evaporated in platinum. It contained 0.46 percent ammonium chloride (NH_4Cl) and 8.64 percent nitrogen trioxide (N_2O_3), found by Kjeldahl method, using salicylic acid. The copper sulphate and sulphuric acid concentrations were likewise the same as in the nitrate solution used for electrolysis in Section XII. Practically all the dissolved gases were removed from the distilled water, and the solution was made up fresh and electrolyzed immediately, to avoid spontaneous decomposition.

Electrical measurements were made as in the reduction of nitrate treated in Section XII;[2] these are given in Table XLVI, under their proper headings. Tables XLVII and XLVIII contain analyses of the anode and cathode gases evolved during each period of electrolysis, reduced to 0° C. and 760 mm. mercury,

* Published by permission of the Secretary of Agriculture.

[1] The sections, tables and figures are numbered so that Sections I, II and III of this work are consecutive. The last table in Section XII was No. XLV, and the last figure No. 14.

allowing for aqueous vapor pressure; Table XLIX shows the concentration of ammonia and of copper in anode and cathode liquor at the end of each period of electrolysis, together with the cubic centimeters of permanganate required to oxidize sach sample of solution before distilling off the ammonia.

TABLE XLVI.

Electrical data. Reduction of hydroxylamine in sulphuric acid solution. Platinum anode, 56.6 sq. cm. area; copper cathode, 100 sq. cm. area.

Current	Time	Cur'nt Amps.	Period of Electrolysis min.	sec.	Interval min.	sec.	Total Period of Electrolysis min.	sec.	Discharge Single Potential Anode Volts	Cathode Volts	Coulombs	Total Coulombs	Temp. of Solution °C
	A. M.												
	8:42	.00	0	0	0	0	0		. . .	—0.483	. .	. .	19.9
	8:43	.00	0	0	1	0	0		—0.716		. .	. .	
	8:46	.00	0	0	4	0	0		.	—0.425		. .	19.9
On	8:53	1.090			. . .		. .		. . .	.	.	. .	. .
	8:54	. . .	1	0	. .				. . .	—0.426	. .	. .	. .
	8:59	1.080	6	0	. . .		6	0	—1.979	. . .	. .	. .	. .
	9:01	. . .	8	0	. .		. .		. . .	+0.054	. .	. .	20.8
	9:02	1.080	9	0	. . .		. .		. . .	+0.109	. .	. .	. .
Off	9:03	1.080	10	0			10	0	. . .	. . .	651	651	. .
	9:33	0.000	. .		30	0				—0.426	. .	. .	.
	9:36	0.000	. .		33	0	. .		—0.789		. .	.	21.1
On	9:38:30	1.105	. .		. .		. .		. . .	. . .	. .	. .	. .
	9:41:30	. . .	3	0	. . .		13	0	—1.886	. .	. .	. .	. .
	9:44	. . .	5	30	. . .		15	30	. . .	+0.110	. .	. .	. .
Off	9:48:30	1.105	10	00	. . .		20	0	. . .	. . .	663	1314	. .
	10:48	0.000	. .		59	30	. .		—0.835	—0.441	. .	.	. .
On	11:08	1.095	. . .		. . .		. . .		. . .	. . .	. .	. .	21.3
	11:10	1.075	2	0	. .		. . .		. . .	. .	. .	. .	. .
	11:13	. . .	5	0	. . .		25	0		+0.167	. .	. .	. .
	11:15		7	0	. . .		27	0	—1.859	. . .	. .	. .	. .
Off	11:18	1.080	10	0	. . .		30	0	. . .	.	647	1961	. .
	P. M.												
	12:08	0.000	. .		50	0	.		. . .	—0.445	. .	. .	. .
	12:09	. . .			51	0	. . .		—0.804	. . .	.	. .	. .
O	12:10	1.095	. . .		. . .		. . .		. . .	. . .	. .	. .	. .
	12:12:30	. . .	. . .		. . .		32	30	—1.746	. . .	. .	. .	. .
	12:14	. .	4		. . .		34		. . .	+0.252	. .	. .	. .
	12:25	1.105	. . .		. . .		. .		. .	. . .	. .	. .	. .
	12:26	. . .	. . .		. . .		46	0	. .	+0.165	. .	. .	. .
	12:28	. . .	. . .		. . .		48	0	—1.831	. . .	. .	. .	. .
Off	12:30	. . .	20	0	. . .		50		. . .		1317	3278	. .

[2] On the Electrolytic Reduction of Nitric Acid, II, Trans. Am. Electrochem. Soc. **15**, 535, (1909). See also *Ibid.*, **12**, 325, (1907).

	1:07	0.000	. . .	. . .	. .	. . .	—0.441	. .	. .	. .
	1:08	0.000	. . .	39 o	. . .	—0.855	. . .	. .	. .	. .
On	1:09	1.090	. . .	. . .	. . .	. . .	. . .	. .	. .	21.8
	1:18	. . .	9 o	. . .	59 o	. . .	+0.251	. .	. .	. .
	1:22	. .	. . .	. . .	63	—2.000	. . .	. .	. .	. .
	1:26	. . .	. . .	. . .	67	—2.000	. .	. .	. .	. .
	1:27	. . .	. . .	. . .	68 o	. . .	+0.194	. .	. .	. .
Off	1:29	1.090	20 o	. . .	70	. .	. . .	1308	4586	. .
	2:23	0.000	. . .	54	. . .	—0.673	—0.428	.		. .
	. . .	. . .	. . .	60 o	. . .		. .	. .	.	. .
On	2:29	1.115	. . .	. . .	. . .	. . .	. . .	. .	. .	22.4
	2:35	. . .	. . .	. .	76	—2.028	. . .	. .	. .	. .
	2:36	. . .	. . .	. . .	77 o	. . .	+0.106	. .	. .	.
	2:38	1.095	. .	. .	. .	. . .	. . .	. .	. .	22.5
	2:45	. . .	. . .	. . .	86 o	—2.056	. . .	. .	. .	. .
	2:46	.	. . .	. . .	87	. . .	+0.106	. .	. .	. .
Off	2:49	1.105	20	. . .	90	. . .	. . .	1324	5910	. .
	3:08	. . .	. . .	19 o	. . .	—0.688	—0.428	. .	. .	. .
	4:51	. . .	. . .	122 o	. . .	—0.672	. . .	. .	. .	. .
	4:52	. . .	. . .	123 o	. . .	. . .	—0.420	. .	. .	. .
	. . .	. . .	. . .	125 o		. . .	. . .	. .	. .	. .
On	4:55	1.165	. . .	. . .	. . .	.	. . .	. .	. .	22.6
	4:58	.	. .	. . .	93	—2.053	. . .	. .	. .	. .
	5:02	. . .	. . .	. . .	97 o	.	+0.016	. .	. .	. .
	5:10	. . .	. . .	. . .	105	—2.110	. . .	. .	. .	. .
	5:12	. . .	. . .	. . .	107 o	. . .	+0.102	.	.	. .
Off	5:15	1.165	20	. .	110	. . .	. . .	1398	7308	. .
	7:35	. . .	. . .	140 o	. . .	. . .	—0.443	. .	. .	. .
	7:39	. . .	. . .	144	. . .	—0.673	. . .	. .	. .	22.1
		. . .	. . .	153 o	. . .	. . .	. . .	. .	. .	. .
On	7:48	1.150	. . .	.	. . .	.	. .	. .	. .	22.4
	7:56	. . .	8	. . .	118	—2.146	. . .	. .	. .	. .
	7:57	. . .	9	. . .	119 o	. .	+0.129	. .	. .	. .
	8:05	. . .	. .	. . .	127	—2.146		. .	. .	. .
	8:06	. . .	. . .	. . .	128 o	. . .	+0.044	. .	. .	. .
Off	8:08	1.150	20	. . .	130	. . .	. . .	1380	8688	. .
	8:22	. . .	. . .	14 o	. . .	. . .	—0.416	. .	. .	. .
	8:23	. . .	. .	15 o		—0.687	. . .	.	. .	. .
On	8:23	1.160	. . .	. . .	. . .	. . .	. . .	. .	. .	22.3
	8:27	. . .	. .	. . .	134	—2.164	. . .	. .	. .	. .
	8:28	. . .	. . .	. . .	135 o	. . .	+0.060	. .	. .	. .
	8:36	. . .	. . .	. . .	143 o	. . .	+0.015	. .	. .	. .
	8:37	. . .	. . .	. . .	144	—2.164	. . .	. .	. .	. .
Off	8:43	. . .	20	. . .	150	. . .	. . .	1392	10070	. .
	8:58	. . .	. . .	15 o	. . .	. . .	—0.428	. .	. .	. .
	8:59	. . .	. . .	16 o	. . .	—0.709	. . .	. .	. .	. .
	9:56	. . .	. . .	73 o	. . .	. . .	—0.442	. .	. .	. .
March 25	9:57	. . .	. . .	74 o	. . .	—0.703	. . .	. .	. .	. .
	A. M.									
	10:45	. . .	. . .	2898 o	. . .	. . .	—0.427	. .	. .	. .
	10:47	. . .	. . .	2900	. . .	—0.702	. . .	. .	. .	. .

TABLE XLVII.

Anode Gases 0° C., 760 mm.

Gas Liberated c.c.	Oxygen			Volume Ratio Percent	Nitrogen			Sample No.
	c.c.	Grams	Total Grams		c.c.	Grams	Total Grams	
11.06	9.61	0.01371	0.01371	87.0	1.45	0.00182	0.00182	1
10.58	9.22	.01317	.02688	87.1	1.36	.00171	.00353	2
10.95	9.50	.01355	.04043	86.7	1.45	.00182	.00535	3
21.7	19.07	.02725	.06768	87.9	2.63	.00330	.00865	4
23.7	21.25	.0302	.0979	89.8	2.45	.00308	.01173	5
25.1	22.38	.0320	.1299	89.6	2.72	.00342	.01515	6
26.75	23.85	.0341	.1640	89.3	2.90	.00364	.01879	7
24.9	22.09	.0316	.1956	88.7	2.81	.00353	.02232	8
26.3	23.94	.0342	.2298	91.0	2.36	.00296	.02528	9

TABLE XLVIII.

Cathode Gases, 0° C.; 760 mm.

Gas Liberated c.c.	Hydrogen			Volume Ratio Percent	Nitrogen			Volume Ratio Percent	Sample No.
	c.c.	Grams	Total Grams		c.c.	Grams	Total Grams		
78.1	39.49	0.00355	0.00355	50.6	38.61	0.0485	0.0485	49.4	1
34.1	22.89	.00206	.00561	67.2	11.21	.0141	.0626	32.8	2
31.6	23.96	.002155	.007765	75.8	7.64	.0096	.0722	24.2	3
81.3	69.7	.00627	.014035	85.7	11.6	.01457	.0868	14.3	4
81.0	65.9	.00594	.019975	81.4	15.1	.01896	.1058	18.6	5
78.2	65.0	.00585	.025825	83.1	13.2	.01658	.1224	16.9	6
76.1	66.0	.00593	.031755	86.7	10.1	.01270	.1351	13.3	7
67.6	61.62	.0055	.039555	91.2	5.98	.00751	.1426	8.8	8
94.3	85.6	.0078	.04736	90.7	8.70	.01092	.1535	9.3	9

TABLE XLIX.

Cathode and anode products in solution.

CATHODE PRODUCTS IN SOLUTION.

Sample No.	Titration for NH_2OH[1]		Nitrogen, as NH_3		Copper Per 50 c.c. of Solution Grams
	$KMnO_4$ Added per 50 c.c. of Sample c.c.	Excess of $KMnO_4$ Over Original Solution Requirement c.c.	Per 50 c.c. of Solution Grams	Percent	
1	72.2	0.3	0.00047	1.32	0.0388
2	79.8	7.9	.00261	7.47	.0376
3	81.0	9.1	.00014	0.40	.0326
4	77.25	5.35	.00028	0.85	.0297
5	78.5	6.6	.0007	2.14	.0296
6	71.5	9.6	.00063	1.96	.0202
7	79.3	7.4	.0007	2.19	.0184
8, 9	76.0	4.1	.00105	3.33	.0152

ANODE PRODUCTS IN SOLUTION.

1	61.4	—10.5	0.00070	1.96	0.0434
2	62.3	— 8.6	.00035	1.00	.0431
3	69.0	— 2.9	.00035	1.01	.0407
4	72.4	+ 0.5	.00021	0.64	.0373
5	67.8	— 4.1	.00047	1.44	.0402
6	70.0	— 1.9	.00047	1.46	.0395
7	75.2	+ 3.3	.00042	1.31	.0360
8, 9	68.5	— 3.4	.00084	2.66	.0296

[1] The $KMnO_4$ solution was exactly tenth normal with respect to oxygen, 1 c.c. contained 0.0008 gram oxygen.

The data contained in Tables XLVII, XLVIII and XLIX, is treated graphically in Figs. 15, 16 and 17, all of which are plotted out on the same time axis (x) using the same scale, while the ordinates for each curve are indicated to the right or left of the figure, and necessarily are in different quantities and on different scales. It should be remembered that all of these curves are for *one solution,* sampled from time to time by withdrawing portions for analysis. The loss of materials thus produced is, of course, taken into account in calculating each point of the curve affected thereby.

Anode Reactions.

Considering Fig. 15, we see that nitrogen gas is liberated at a constant rate upon the platinum anode, while there is a slight increase in the current density, from 0.0193 amperes per sq. cm.

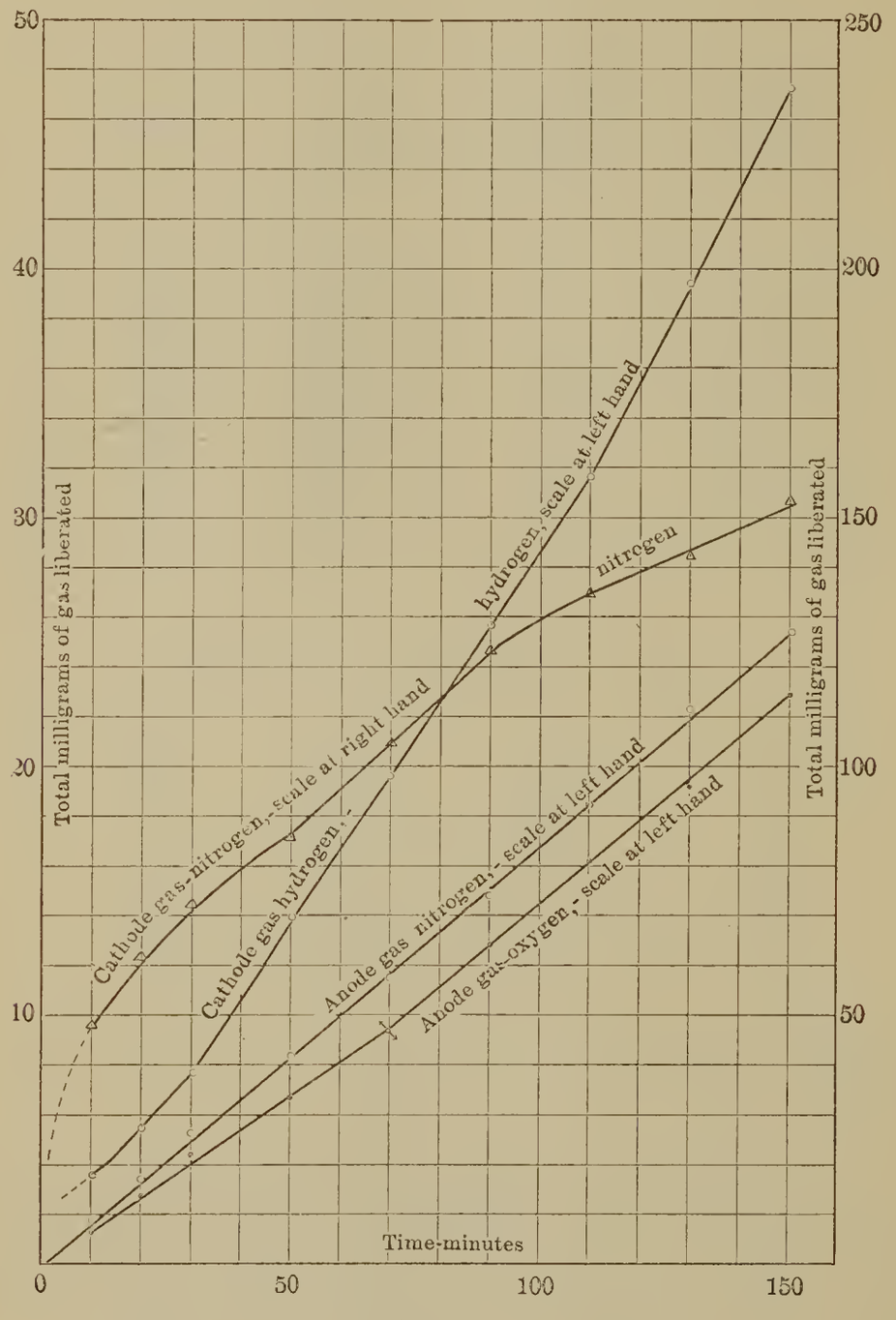


FIG. 15.

to 0.0205, during the period of electrolysis—an increase of some 6 percent. It should be noted, however, that integration of the current readings to give the coulombs passed through the cell shows a constant average current for the first 90 minutes of electrolysis—as shown by the arrow, Fig. 18—consequently, the

coulombs used to liberate nitrogen is a constant fraction of the total coulombs passed during that period.

Returning to Fig. 15, it is evident that oxygen gas is liberated

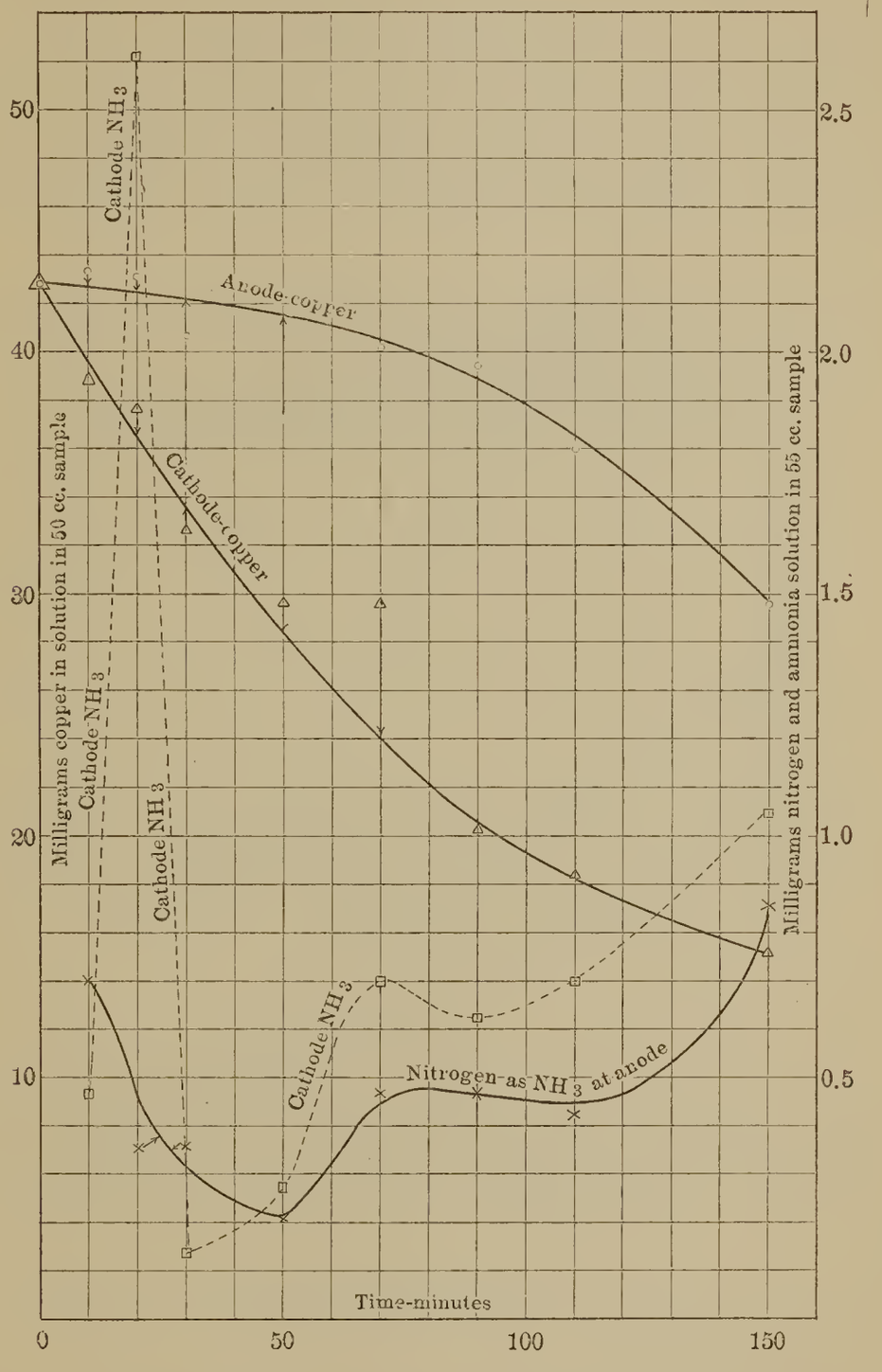


FIG. 16.

at the anode at a constant rate during the first 70 minutes. The rate of oxygen evolution changes at this point, but is constant for the rest of the period of electrolysis, as might be expected from the curve for total coulombs (Fig. 18) which changes its direc-

tion between the 70 and 90 minute points and then again becomes a straight line.

We are not in a position to state exactly the chemical reactions taking place at the anode. The substances which may be present are (using structural formulæ for brevity) $NH_2OH.HCl$, O_x, $N_2O_3(H_2O)_x$, Cl_x, H_2SO_4,HCl,$(NH_2OH)_2SO_4$, $CuSO_4$.

The oxygen will act upon the $N_2O_3.(H_2O)_x$ to form (N_2O_5)-$(H_2O)_x$; also upon the hydroxylamine, giving nitrogen and ammonia and water; this ammonia in turn is oxidized to nitro-

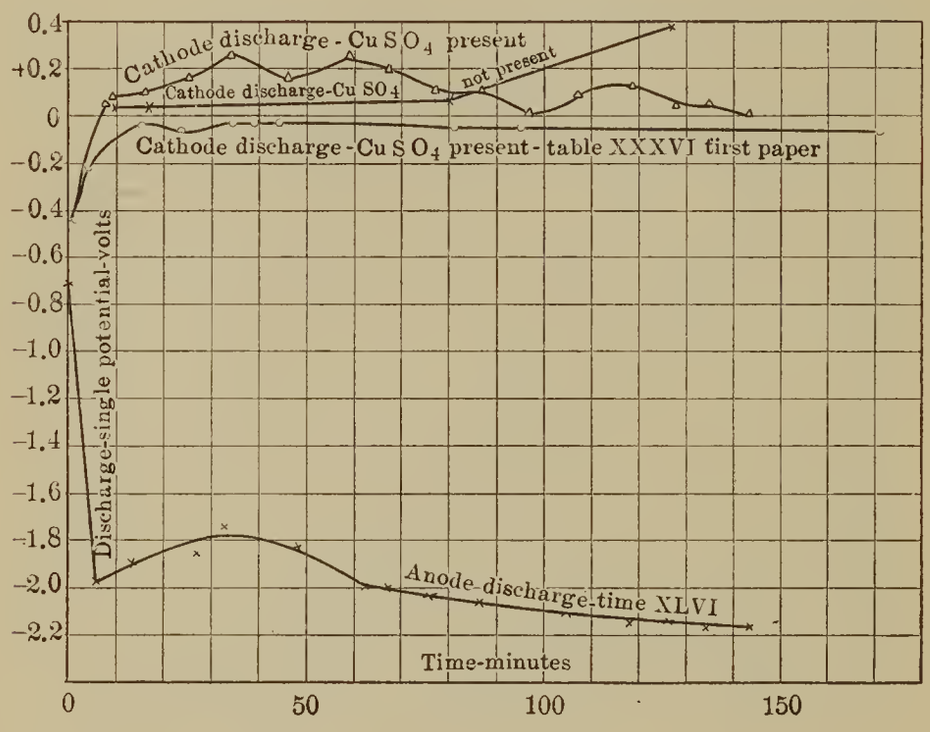


FIG. 17.

gen,[3] hydroxylamine,[4] water and undetermined bodies; the oxygen and chlorine may react to give chlorine oxy-acids, which would act upon the hydroxylamine and other oxidizable substances present.

The N_2O_3 will react upon hydroxylamine, giving nitrogen, among other products.

The solution is acid throughout the period of electrolysis, so the action of chlorine upon ammonia is not in evidence.

Fig. 16 shows the concentration of ammonia at the anode dur-

[3] See Section XI of the second paper, Trans. Am. Electrochem. Soc., **15**, 538, (1909).

[4] See Section XI, pages 540 and 541; and Section XII, Fig. 11, page 546, and Table XLII, page 544, *Ibid.*, **15**, (1909).

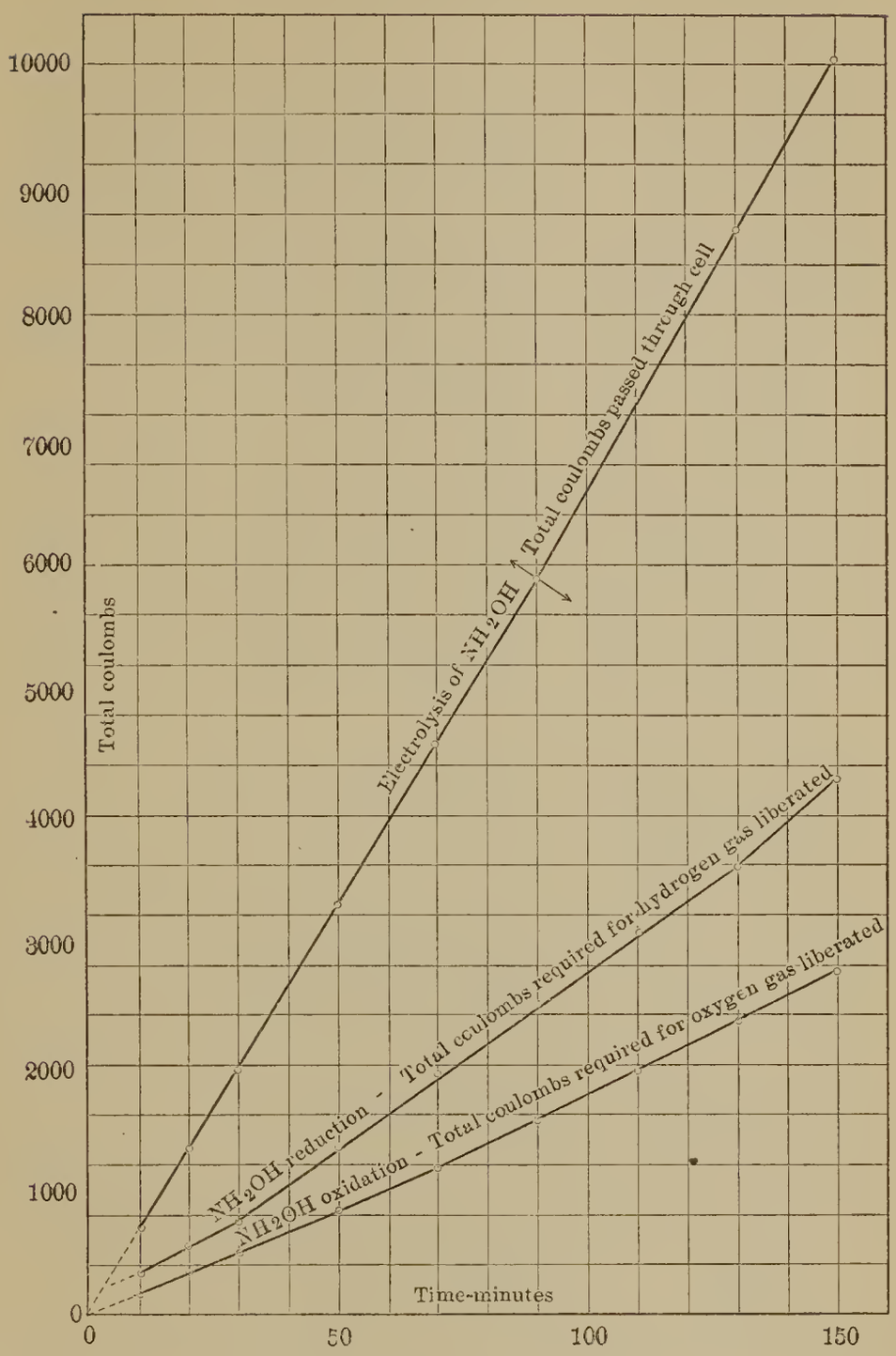


FIG. 18.

ing the different periods of electrolysis. The quantity of ammonia thus formed from hydroxylamine is large, compared to the quantity of nitrogen given off at the anode, being from 10 to 27 times greater, as shown in Table L, columns IX and XII.

TABLE L.

Derived data on anode and cathode reaction products in the reduction of hydroxylamine.

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
Total Period of Electrolysis Minutes	Total Solution Left c.c.	Nitrogen Lost as Gas Anode + Cathode (increm't) Grams	Total Nitrogen Left in Entire Solution	Total Nitrogen in 50 c.c. Solution average of Anode and Cathode Liquor Grams	Loss of Nitrogen Gas at Anode Increment Per 50 c.c. of Solution Grams	Total Nitrogen in 50 c.c. of Solution at Start of Each Period of Electrolysis Grams	Nitrogen in Solution at Anode as NH_3 in 50 c.c. Grams	Percent. of Total Nitrogen as NH_3 in Anode Liquor	Nitrogen in Solution at Cathode as NH_3 in 50 c.c. Grams	Percent. of Total Nitrogen as NH_3 in Cathode Liquor	Percent. of Total Nitrogen Lost at Anode as Gas (Increm't)	Percent. of Total Nitrogen Lost at Cathode as Gas (Increm't)
0	3400	0	2.4254	0.03567	. . . .	. . . .	. . . .	. . .	. . . .	. .	. . . .	. . .
10	3400	0.05032	2.3751	.03493	0.0000268	0.03567	0.00070	1.96	0.00047	1.32	0.075	2.00
20	3296	.01581	2.2865	.03470	.0000260	.03493	.00035	1.00	.00261	7.47	0.072	0.59
30	3192	.01142	2.1002	.03292	.0000285	.03470	.00035	1.01	.00014	0.40	0.080	0.33
50	3088	.01787	2.0138	.03260	.0000534	.03292	.00021	0.64	.00028	0.85	0.157	0.64
70	2988	.02204	1.9274	.03221	.0000515	.03260	.00047	1.44	.00070	2.14	0.153	0.90
90	2888	.02000	1.8436	.03190	.0000592	.03221	.00047	1.46	.00063	1.96	0.177	0.86
110	2788	.01634	1.7640	.03163	.0000653	.03190	.00042	1.31	.00070	2.19	0.197	0.69
130	. . .	.01104	. . . .	. . . .	.0000634	. . . .	. . . .	. . .	. . . .	. . .	0.205	0.43
150	2688	.01388	1.6767	.03120	.0000550	.03163	.00084	2.66	.00105	3.33	0.176	0.64
											Total Loss of Nitrogen as Gas at Anode in Percent.	Total Loss of Nitrogen as Gas at Cathode in Percent.
											1.292	7.08

Table LI.

Apportionment of coulombs in the reduction of NH_2OH.

Total Period of Electrolysis. Minutes	Period of Electrolysis. Minutes	Total Coulombs. Milliammeter	Coulombs for each Period of Electrolysis	Total Coulombs required for Oxygen Gas at Anode	Coulombs required for Oxygen Gas liberated at Anode. Each period	Total Coulombs used in Oxidation	Coulombs used in Oxidation. Each Period	Total Coulombs required for Hydrogen Gas at Cathode	Coulombs required for Hydrogen Gas. Each Period	Total Coulombs used in Reduction	Coulombs used in Reduction. Each Period
10	10	651	651	165	165	486	486	340	340	311	311
20	10	1314	663	324	159	990	504	538	198	776	465
30	10	1961	647	488	164	1473	483	745	207	1246	440
50	20	3278	1317	817	329	2461	988	1346	601	1962	716
70	20	4586	1308	1182	365	3394	933	1916	570	2700	738
90	20	5910	1324	1568	386	4332	938	2477	561	3463	763
110	20	7308	1398	1980	412	4318	986	3045	568	4193	730
130	20	8688	1380	2362	382	5316	998	3572	527	5046	853
150	20	10070	1392	2775	413	6295	979	4320	748	5580	544

The discharge single potential at the anode shown in Fig. 17 has the same general form as curve 2, Fig. 7, in the first paper,[5] but lies lower (higher negative values); this is probably due to the presence of copper sulphate in rather higher concentration, and to the better stirring in this present work, produced by withdrawal of solution for analysis from time to time. Curve 3, Fig. 7, lies still lower; here the copper sulphate concentration was five times that in curve 2, Fig. 7. When no copper sulphate at all is present, the anode discharge remains higher, near to the value of oxygen—1.4 volts, for some 80 minutes of electrolysis. See curve 1, Fig. 7.

Fig. 18 shows the coulombs equivalent to the oxygen liberated from the anode.

Cathode Reactions.

The curves given in Fig. 15 show that both hydrogen and nitrogen gases coming from the cathode are evolved in much greater quantity during the first periods of electrolysis than later. With an average current of 1.082 amperes during the first 10 minutes, 0.00677 gram of hydrogen should be liberated, using 0.00001043 gram hydrogen per second per ampere as a unit. But only 0.00355

[5] Trans. Am. Electrochem. Soc., **12**, 394, (1907).

gram hydrogen actually was evolved, leaving some 0.00322 gram, or 47.6 percent, as the hydrogen used in reduction.

Now the nitrogen gas evolved at the cathode during this period weighed 0.0485 gram, while the nitrogen gas collected during the second 10-minute period of electrolysis weighed only 0.0141 gram.

This nitrogen comes partly from oxidation of the hydroxylamine by nitrogen trioxide in acid solution; but the rate of evolution here observed is greater than would be occasioned by such action at this temperature. The N_2O_3 is present in solution in the ratio of 0.114 gram molecular weight to 1.3 gram molecular weight of NH_2OH, and this indicates, too, the insufficiency of this reaction to account for the nitrogen evolved.

Referring to Table XLIX, we see that the nitrogen as ammonia in solution in the cathode liquor was only 1.32 percent of the total nitrogen at the end of the first 10-minute period, while at the end of the second 10-minute period some 7.5 percent was formed.

It may be that this NH_2OH reduction takes place in stages, as does the reduction of nitrobenzene. It is conceivable that we have hydrazine formed:

(a) $2NH_2OH + 2H = N_2H_4 + 2H_2O$

and then the oxidation of this hydrazine by hydroxylamine,

(b) $N_2H_4 + 2NH_2OH \longrightarrow N_2 + 2NH_3 + 2H_2O$.

This theory requires a loss of 50 percent of the nitrogen as gas when hydroxylamine is reduced to ammonia. Consider now that there was liberated during the first ten minutes of electrolysis, as shown in Table XLIX, 0.0485 gram nitrogen, while, according to the milliammeter, 651.6 coulombs passed. Of this quantity of electricity, the hydrogen gas collected (0.00355 gram) required only 340 coulombs, leaving 311.6 coulombs used in reduction.

Inspection of equations (a) and (b) above shows that the N_2 liberated in equation *b* corresponds to H_2 required for reduction in equation *a*. In this 10-minute run (Table XLVIII) 0.0485 gram of nitrogen gas, therefore, might correspond to 0.00349 gram of hydrogen required for the first stage where hydroxylamine is reduced to hydrazine. Since one coulomb liberates 0.00001043 gram hydrogen, this corresponds to 355 coulombs, whereas 311.6 coulombs were actually used in the reduction, according to the ammeter measurements just cited. The

deposition of copper, too, must be considered in accounting for the coulombs. Fifty c.c. of cathode solution lost 0.0012 gram copper in the first 10 minutes. Assuming that this loss extended to some 800 c.c. of solution in the neighborhood of the cathode (the anode solution showed a drop of only 0.0003 gram copper per 50 c.c.), the total copper deposited was some 0.02 gram, which would require about 61 coulombs. The total quantity of electricity remaining unaccounted for is then about —85 coulombs. The uncertain factors in this calculation are the quantity of copper deposited and the quantity of ammonia actually formed. We have only the concentration of 50 c.c. of the cathode solution with respect to each of these, and as the ammonia diffuses rapidly it is difficult to estimate the exact quantity formed, the total volume of solution being 3400 c.c.; and besides this, ammonia is formed in considerable quantity at the anode, thus obscuring the quantity of ammonia due to the cathode reactions.

Referring back to the results given in Table XLIII, page 545 of the second paper,[6] it is seen that in the reduction of nitrate this same phenomena appears: during the first 10 minutes of electrolysis 0.0000611 gram hydrogen was evolved and 0.0061 gram nitrogen, at the cathode, whereas during the next 118 minutes only 0.0001089 gram hydrogen was collected, and only 0.00041 gram of nitrogen gas. Bearing in mind the fact that hydroxylamine is formed at the cathode, and that N_2O_3 is also probably present, as well as nitrate, it is seen that the first stages in the electrolytic reduction of a nitrate solution containing sulphuric acid and copper sulphate, are comparable to the reduction of hydroxylamine under the same conditions—save that hydrochloric acid is present. It seems unlikely that free hydrochloric acid would materially alter the conditions at the cathode, although its effect at the anode might be disturbing.

The work done upon the cathode reactions shows, however, that ammonia is formed from hydroxylamine, but not quantitatively, since nitrogen gas is given off.

Cathode discharge single potentials are given in Fig. 18, together with comparison curves taken from the first paper.[7] The cathode discharge here is a little higher.

[6] *L. c.*
[7] *L. c.*

The excess of permanganate required for the cathode solution is positive throughout (Table XLIX), and shows a rough correspondence to the deficiency in permanganate requirement for the anode solutions. Evidently the tendency of the hydroxylamine salt to increase in concentration (migration) about the cathode is a major factor in this effect.

Aside from speculation, the meaning of the increase in the quantity of permanganate required to titrate the anode and cathode liquor as electrolysis proceeds is not clear. More work is needed here, and would be forthcoming at this time but for the pressure of other duties.

SUMMARY.

In this paper it is shown again that hydroxylamine may be reduced to ammonia at a copper cathode in presence of copper sulphate, sulphuric acid and hydrochloric acid.

Nitrogen is liberated at both anode and cathode. The rate of this liberation has been studied quantitatively: Nitrogen is evolved at the anode at a fairly constant rate, ammonia being left in solution; at the cathode, nitrogen is set free rapidly at first, and in such quantity as to suggest the possibility of the formation of hydrazine as an intermediate step, and its subsequent oxidation by hydroxylamine, thus producing free nitrogen. As electrolysis proceeds, this formation of nitrogen gas decreases.

This initial evolution of free nitrogen in quantity is also met in the electrolytic reduction of nitrate under the same conditions, and suggests that the hydroxylamine formed in the reduction of nitrate may in that case, too, be reduced to a lower stage of oxidation, such as hydrazine.

Single potential discharge measurements from cathode and from anode are given.

Bureau of Soils,
U. S. Department of Agriculture,
April 10, 1910.

A paper presented at the Seventeenth General Meeting of the American Electrochemical Society in Pittsburgh, Pa., May 7, 1910, President L. H. Baekeland in the Chair.

THE EFFECT OF MOISTURE AND OF SOLUTIONS UPON THE ELECTRIC CONDUCTIVITY OF SOILS*

By R. O. E. Davis.

The electrical method used by the Bureau of Soils for the determination of soluble salts in a soil has been described before the American Electrochemical Society by F. K. Cameron,[1] and in bulletins by Whitney and Means,[2] and by Briggs.[3] A number of experiments have been made lately in further studying this method. I wish to present some of the data concerning the conductivity of the soil and the conditions most favorable for the conduction of the current.

I have made measurements of the resistivity of several types of soil when air-dried and when saturated with distilled water. Using the rubber cup designed for field work, with electrodes 2.5 x 4.1 cm. and 3.5 cm. apart, the following results were obtained, the resistivity (specific resistance) being given throughout in ohms per centimeter/square centimeter, and the conductivity (specific conductance) being for the same dimensions in reciprocal ohms.

Table I.

Soil	Dry	Wet	
	Resistivity above	Resistivity	Conductivity × 10,000
Quartz Sand	35600	4281	2.33
Quartz Powder	35600	3620	2.76
Cecil Sandy Loam	36200	1483	6.74
Norfolk Loam	36620	2013	4.97
Sharkey Clay	36620	638	15.67
Cecil Clay	36620	3151	3.17
Portsmouth Sand	36620	1743	5.74

* Published by permission of the Secretary of Agriculture.

[1] Trans. **15**, 559 (1909).

[2] Bull. No. 8, Division of Soils, U. S. Dept. of Agriculture (1897).

[3] Bull. No. 15, Division of Soils, U. S. Dept. of Agriculture (1899).

In addition to there being an enormous difference between the dry and wet soil, there will also be noticed a considerable difference between the amount of resistance offered by the types of wet soils. No really satisfactory method has been devised for measuring the resistance of soils without disturbing them, but Whitney, Gardner and Briggs[4] give interesting results from some measurements of a limestone soil near Lexington, Ky., covering a period of nearly four months, from July 1st to October 14th. Briefly, they found that for the first three inches of soil the resistivity varied from 461 to 2,036 ohms, for the soil depth 3-6 inches, from 471 (following rainfall of 1.76 inches) to 1.083 ohms, and for soil depth 21-24 inches, from 894 to 1,162. The low resistivity followed a period of heavy rainfall; and it was rather remarkable that from August 25th to October 14th the maximum difference at the depth of two feet was 59 ohms. The rainfall during the whole period varied. Within two days (September 28th-29th) there was a rainfall of 3.25 inches, while for the twenty days preceding there was only about 1.00 inch, and within four days preceding the dry period a rainfall of 5.60 inches. This would seem to indicate that at a depth of two feet or more the conductivity for a given type of soil is practically constant.

TABLE II.

Per Cent. H_2O	Loam		Heavy Loam	
	Resistivity	Conductivity ×10,000	Resistivity	Conductivity ×10,000
20	7261	1.377	10790	0.927
19	7595	1.317	11620	0.860
18	8090	1.236	12660	0.790
17	8549	1.170	14010	0.714
16	9170	1.090	16140	0.620
15	10000	1.000	19250	0.518
14	11100	0.900	23240	0.430
13	12570	.796	28531	0.350
12	14440	.693	35010	0.285
11	16720	.598	42940	0.233
10	19790	.505	55400	0.180

Now, I have pointed out that water affects the conductivity of a soil very greatly, but the quantitative relation may be shown

[4] Bull. No. 6, p. 22, Division of Soils, U. S. Dept. of Agriculture.

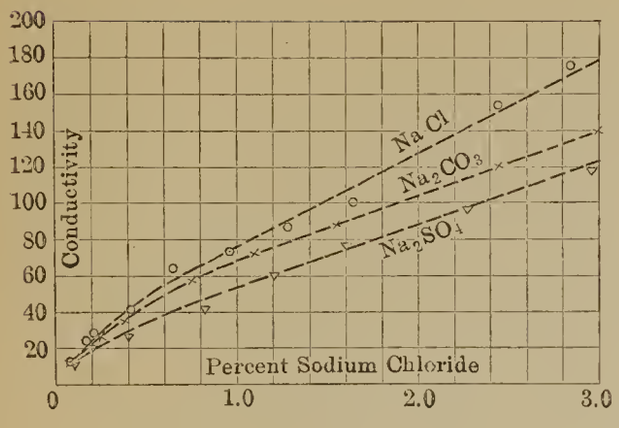


FIG. 1. Quartz Sand.

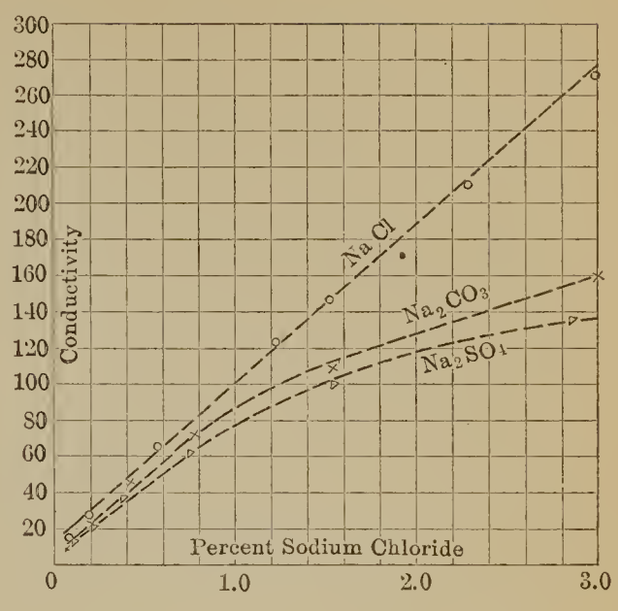


FIG. 2. Portsmouth Sand.

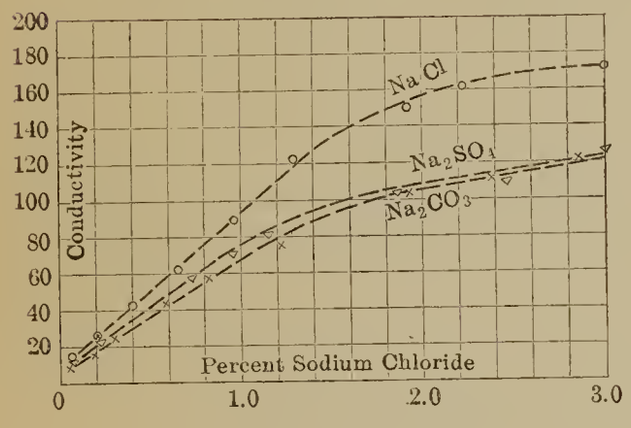


FIG. 3. Sandy Loam.

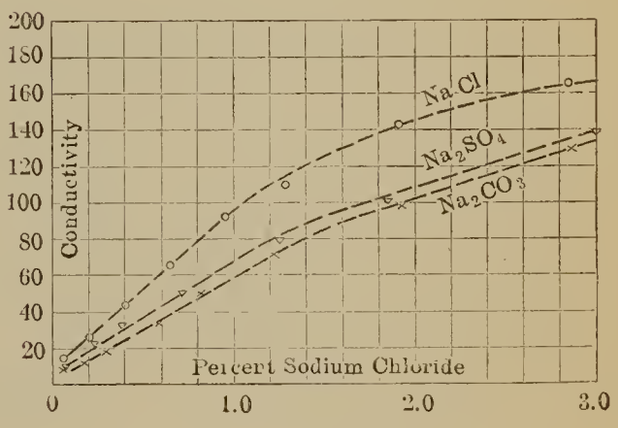


FIG. 4. Loam.

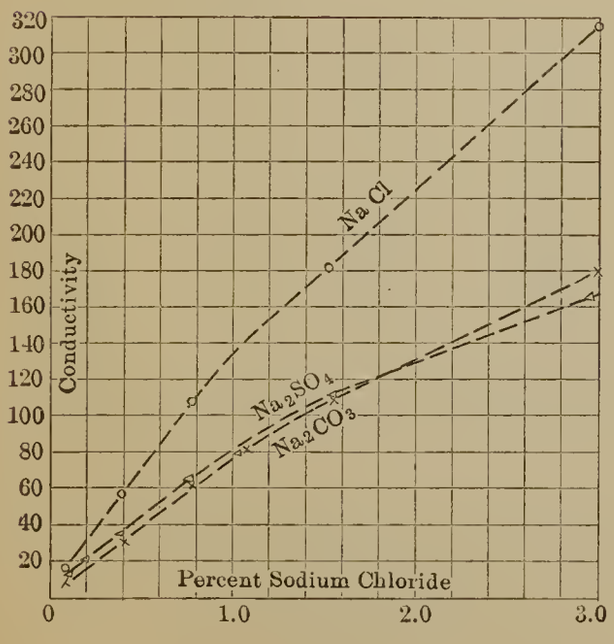


FIG. 5. Light Clay.

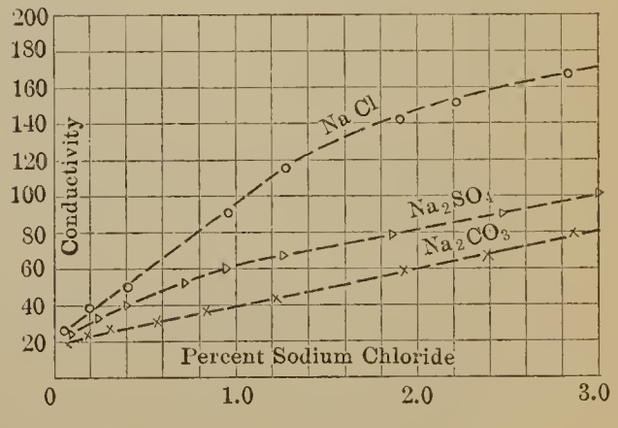


FIG. 6. Heavy Clay.

better by results given by Whitney and Means.[5] The resistivity and conductivity of some soils for percentages of water from 10 to 20, which are the actual ranges in the field, are given in Table II. The resistivity-water curves approximate to hyperbolas, and the conductivity-water curves are nearly straight lines; that is, the conductivity varies directly as the amount of moisture in the soil up to saturation, the slope of the curve being different for the individual soils.

I have made a number of measurements of different types of soils with several salts, and my results show that in most cases the conductivity varies almost directly as the amount of salt in the soil, and hence the conductivity-salt curves approximate straight lines. These are shown in Figs. 1 to 6. There will be noticed differences in the conductivity, depending on both the type of soil and the salt.

Effect of Texture on Conductivity.

In an earlier article, Means and Whitney[6] give some results to show the effect of texture upon electrical resistivity, as follows:

Table III.

Salt in all soils 0.5 mg. per gram of soil.

Soil	Resistivity 12 per cent. H_2O	Resistivity Sat'd with H_2O	Surface Area of 1 gm. in sq. cm.	[1]Ratio	
				Surface Area	[2]Resis'y
Early Truck, Md. . .	4080	399	600	15	28
3 Parts Early Truck, Md. } 1 Part Limestone, Va. . . }	7190	477	2212	54	50
2 Parts Early Truck, Md. } 1 Part Limestone, Va. . . }	9000	496	2749	67	62
Limestone, Pa.	14440	554	4089	100	100
" Ky.	14820	563	4339	106	103
" Va., (60% clay)	40670	699	7048	172	282

[1] Comparison of surface area, taking that of Limestone, Pa., as 100.
[2] Comparison of resistivity of soils saturated with water, taking resistivity of Limestone, Pa., as 100.

From this table it is seen that with the same (12 per cent. H_2O) per cent. of moisture and salt content, the fine limestone, with 60

[5] Bull. No. 8, p. 16, Division of Soils, U. S. Dept. of Agriculture.
[6] Bull. No. 8, p. 21, Division of Soils, U. S. Dept. of Agriculture.

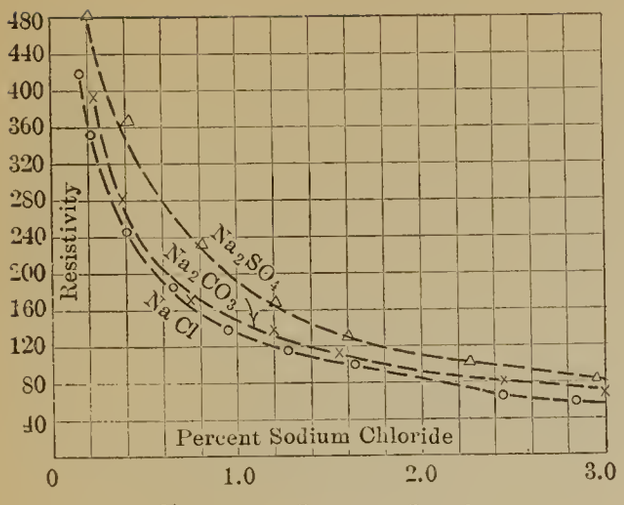


FIG. 7. Quartz Sand.

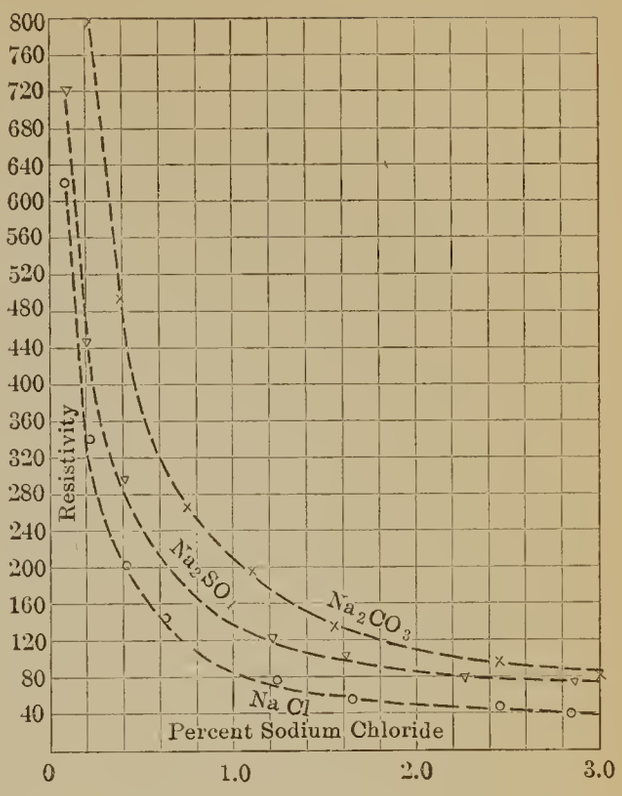


FIG. 8. Portsmouth Sand.

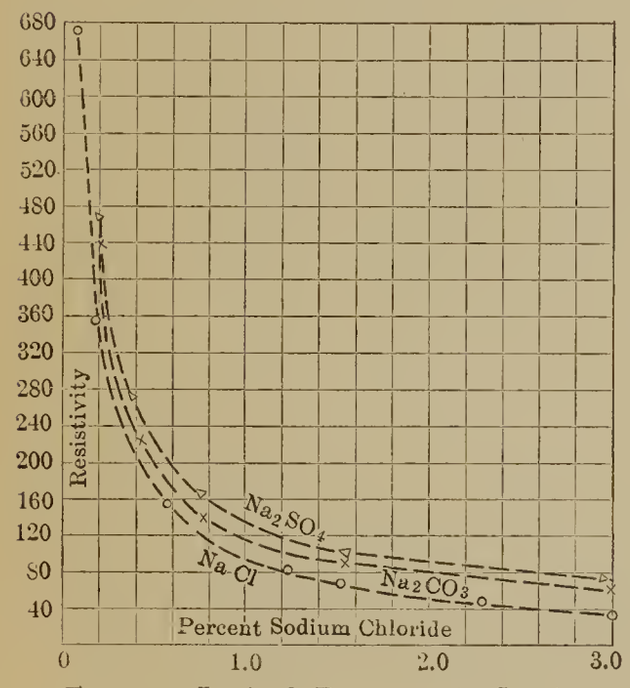


FIG. 9. Ignited Portsmouth Sand.

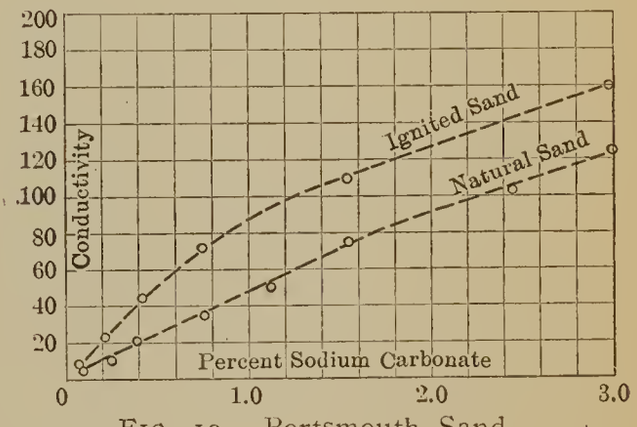


FIG. 10. Portsmouth Sand.

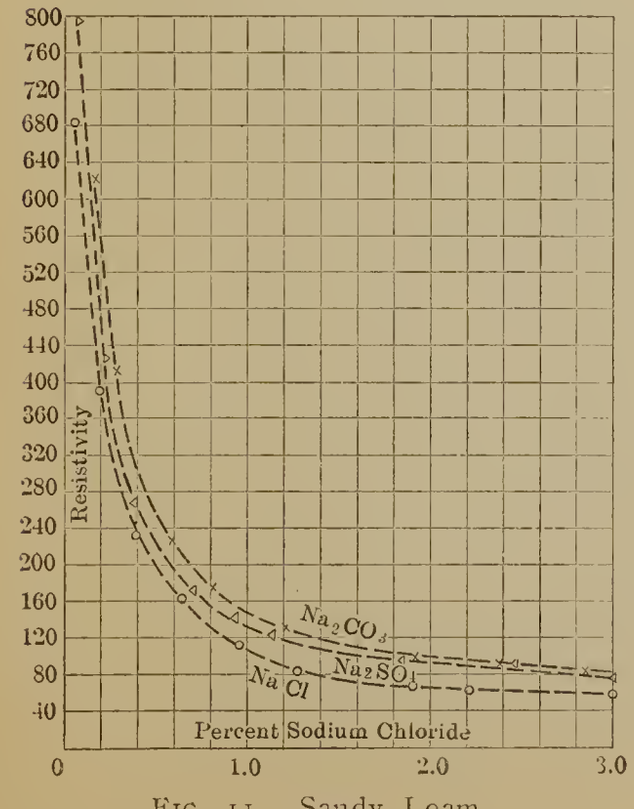


FIG. 11. Sandy Loam.

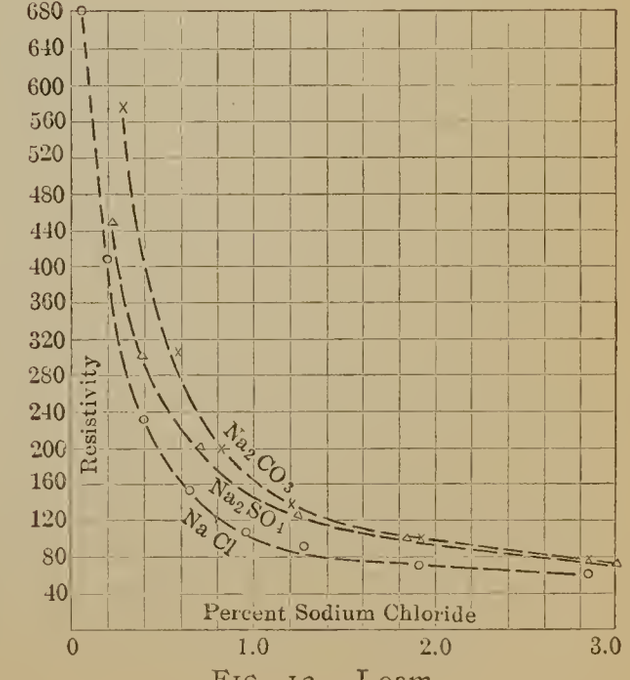


FIG. 12. Loam.

per cent. clay, has nearly ten times the resistivity of the early truck, with five per cent. clay. When saturated with water, the resistivity of the limestone is nearly twice as great as the early truck. The surface area of the limestone is over ten times that of the early truck, so that apparently with water content less than saturation of the soil, the resistivity varies almost directly as the surface area of the soil. But there is a marked change in the ratio when the region of saturation is approached.

The explanation of these results, along with others, may possibly be as follows: The grains of soil, which are themselves fairly good insulators, of course have the effect of lengthening the path of the current passing through the soil—solution films which cover these grains. Hence, the larger the number of soil grains in a given volume of soil, the longer the path of the current, and the greater the resistivity. This remains true until the region of saturation is reached, when the film of water around each grain merges into the soil water, filling the spaces between the grains. The path of the current is thus greatly shortened and resistivity is less. Now, if the salt in solution is concentrated upon the surface of the grains, these films will have the effect of a metallic conductor, or, rather, of grains of soil coated with a metallic conductor, and the resistance to the passage of the current will be decreased, due to increased conductance of this layer. Under these conditions the interstitial solution will not be homogeneous, but will consist of two layers: (1) The more concentrated, better conducting layers about the surface of each grain, and (2) the less concentrated solution partially filling the space between the grains. The measured conductivity will then be made up of two quantities, consisting of the conductance of each of the two layers. The quantity of soluble salts concentrated in the film of water immediately on the soil grains depends upon the nature of the salts in the soil, upon the chemical and physical character of the soil grains, and upon the temperature.

Patten[7] in several articles has shown that there is a concentration of soluble salts in the film of water on the surface of finely-divided powders.

A number of experiments were made on this basis. Solutions of known strength were taken, and to different portions were

[7] Electrochem. and Met. Ind., **5**, 257, 1907; Bull. No. 52, Bureau of Soils, U. S. Dept. of Agriculture, p. 62 (1908); Trans. Am. Electrochem. Soc., **10**, 67 (1906).

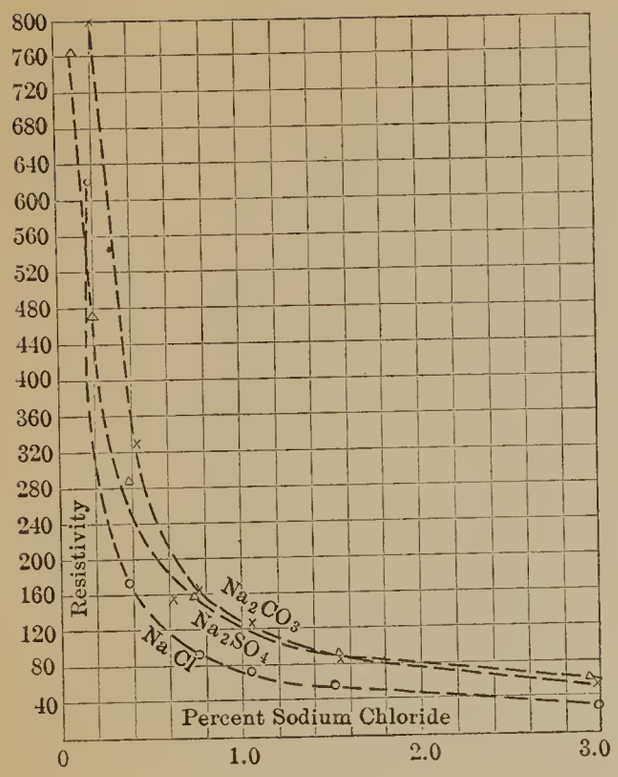


FIG. 13. Clay.

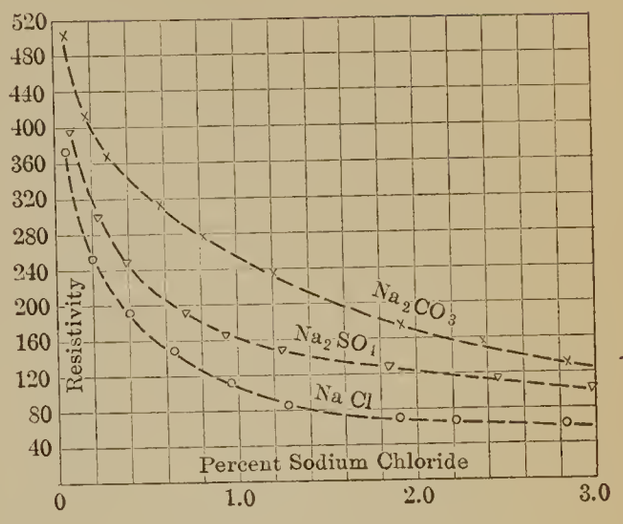


FIG. 14. Heavy Clay.

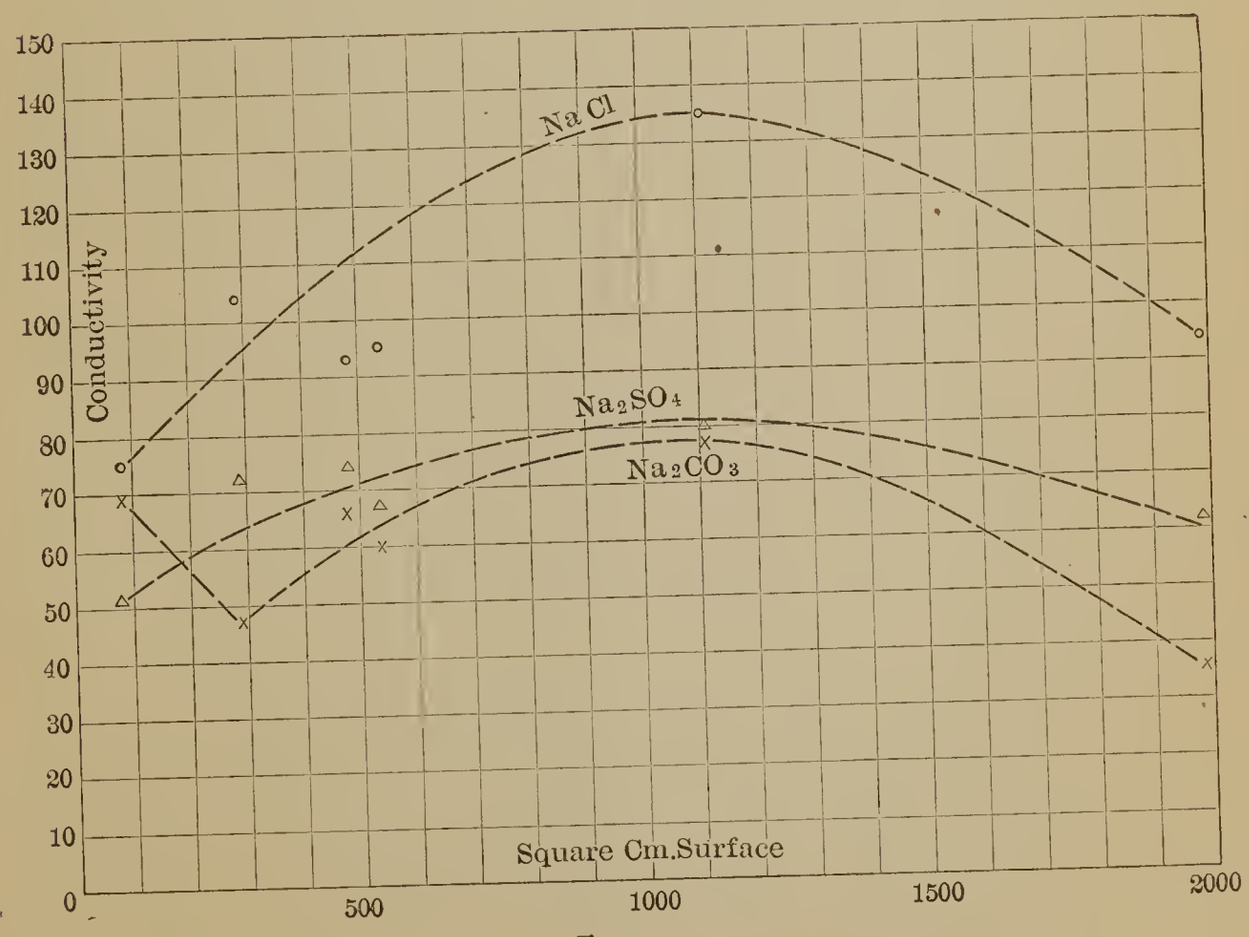


FIG. 15.

added silt, clay, fine quartz flour and ground hematite. This was then centrifuged. The conductivity of the solution was determined before the suspensions were added, then again after centrifuging. The cell used was a large test tube supplied with rigid platinum electrodes, 14 x 5 mm. and 8 mm. apart. With this cell it was impossible to detect any differences in conductivity of solutions of sodium sulphate and chloride before and after adding the suspensions, but in the case of sodium carbonate, the conductivity after removing the suspension of clay and silt was slightly less than before adding. Quartz and hematite showed no difference. This indicated that there was a condensation of dissolved particles on the surface of the suspended grains, and on centrifuging this was carried out of the solution, thereby reducing the conductivity. It is probable that in the case of the chloride and sulphate there is also a condensation, not so marked as with the carbonate, and hence not changing the conductivity enough for the difference to be measured with the cell employed.

Still another factor entering to change the conductivity is the larger amount of soluble material going into solution, due to the greater surface in the case of clays, silts, etc., exposed to the solvent action of water. To determine the effect of soil texture upon the electrical conductivity, several types of soil mixed with various quantities of soluble salts were saturated with water and their conductivity determined. These readings are given in Table IV, and shown graphically in Figs. 1-14.

The measurements on the soils in Table IV do not show clearly the effect of texture, because several of the soils are not representative types. In the accompanying table are given some later measurements on what are considered to be representative soil types. The measurements were made with a mixture of sodium chloride and sulphate in equal parts in the soil and with sodium carbonate alone.

To examine the relation of electrical conductivity to surface area, the resistivity and conductivity of several types of soil are taken by interpolation of curves in Figs. 7, 11, 12, 13 and 14 at one per cent. salt content, each soil being saturated with water. The salt percentage is reckoned on the air-dry weight of the soil. These interpolated values are given in Table VI:

TABLE V.

Percent	Sand		Loam		Clay loam		Clay	
NaCl and Na_2SO_4	Resistivity	Conductivity	Resistivity	Conductivity	Resistivity	Conductivity	Resistivity	Conductivity
0.20	475	21	500	20	515	19	545	18
.40	262	38	272	37	290	34	308	32
.60	177	57	180	56	194	52	214	47
1.00	102	98	115	87	130	77	139	72
3.00	56	178	56	178	59	169	66	152
Na_2CO_3								
0.20	850	12	978	10	1175	9	1180	8
.40	412	24	525	19	632	16	676	15
.60	258	39	360	28	392	26	473	21
1.00	171	58	214	47	217	46	300	33
3.00	74	135	77	130	77	130	94	106

TABLE VI.

At saturation ($t = 15.5°$ C.).

Soil	Sq. Cm. Area Surface per Gm.	Area Ratio	Resistivity	Conductivity $\times 10{,}000$	Res. Ratio	Cond. Ratio	Res. without Salt
1 Per Cent. NaCl.							
Quartz Sand	80	1.00	133	75	1.00	1.00	4281
P. Sand	289	3.61	96	103	.72	1.39	1743
Sandy Loam	478	5.97	107	93	.80	1.24	1483
Loam	536	6.70	105	95	.79	1.27	2012
Clay	1108	13.85	74	135	.56	1.80	3151
Heavy Clay	1984	24.80	106	94	.80	1.25	638
1 Per Cent. Na_2SO_4.							
Quartz Sand	. . .	. . .	196	51	1.00	1.00	. .
P. Sand	. . .	. . .	139	72	.71	1.41	. . .
Sandy Loam	. . .	. . .	136	74	.69	1.45	. . .
Loam	. . .	. . .	149	67	.76	1.31	. . .
Clay	. . .	. . .	125	80	.64	1.57	. . .
Heavy Clay	. . .	. . .	162	62	.83	1.21	. . .
1 Per Cent. Na_2CO_3.							
Quartz Sand	. . .	. . .	146	69	1.00	1.00	. .
P. Sand	. . .	. . .	212	47	1.45	.68	. . .
Sandy Loam	. . .	. . .	151	66	1.03	.95	. . .
Loam	. . .	. . .	166	60	1.14	.87	. . .
Clay	. . .	. . .	130	77	.88	1.12	. . .
Heavy Clay	. . .	. . .	279	36	1.91	.52	. . .

From the table it is noticed that the conductivity with one per cent. salt shows a fairly regular dependence on the increase of surface area. In the cases of Portsmouth sand and heavy clay exceptions occur. Taking the values for quartz sand in each case as unity, the others are compared with it. With sodium chloride the conductivity ratios thus obtained show high values for clay and Portsmouth sand; with sodium sulphate the conductivity ratio for clay alone is high; but with sodium carbonate the ratio for Portsmouth sand is low and that for clay high, while for heavy clay it is very low. The reason for this difference may be due to some physical change in the soil caused by sodium carbonate, or it may be due to organic matter, as discussed below. It is evident that with sodium carbonate the results are different from those with other salts.

In Fig. 15 are plotted curves for one per cent. salt, using as abscissas conductivity, and as ordinates square centimeters surface per gram of soil. The same general character of curve is exhibited by each salt.

Effect of Organic Matter.

It has been suspected for some time that organic matter, or humus, as it occurs naturally, has an effect upon the conductivity of the soil. To test this some experiments were made upon Portsmouth sand, which contained considerable organic matter, about 4.17 per cent. of its air-dried weight. The curves for resistivity and conductivity of Portsmouth sand and sodium chloride, sulphate and carbonate are given (Figs. 2 and 8). Another portion of the same sand was ignited to remove organic matter, and then a new set of curves made with the ignited sand. These are shown in Table IV and in Fig. 9. It is seen that the curves with sodium chloride (NaCl) and sodium sulphate (Na_2SO_4) are practically identical in the natural and ignited sand, but there is a marked difference in the case of Na_2CO_3. This is shown separately in Fig. 10. The difference in the case of carbonate may be due, again, to its power of causing some physical change in the soil. That this increase in conductivity of the ignited sand is not due to material rendered soluble by ignition is shown by the fact that the conductivity of soil contain-

TABLE IV.

Quartz Sand (80 Sq. Cm. Surface per Gm.)			Portsmouth Sand (289 Sq. Cm. Surface per Gm.)			Ignited Portsmouth Saud			Sandy Loam (478 Sq. Cm. Surface Per Gm.)			Loam (536 Sq. Cm. Surface Per Gm.)			Clay (1108 Sq. Cm. Surface Per Gm.)			Heavy Clay (1984 Sq. Cm. Surface Per Gm.)		
Per cent. NaCl	Resistivity	Conductivity ×10,000	Per cent. NaCl	Resistivity	Conductivity ×10,000	Per cent. NaCl	Resistivity	Conductivity ×10,000	Per cent. NaCl	Resistivity	Conductivity ×10,000	Per cent. NaCl	Resistivity	Conductivity ×10,000	Per cent. NaCl	Resistivity	Conductivity ×10,000	Per cent. NaCl	Resistivity	Conductivity ×10,000
0.08	893	11	0.08	622	16	0.08	670	15	0.06	685	15	0.06	680	15	0.08	622	16	0.06	373	27
.17	418	24	.21	342	41	.19	359	28	.20	391	26	.20	408	25	.39	173	58	.20	252	40
.21	352	28	.41	203	49	.57	154	65	.40	234	43	.40	233	43	.77	92	108	.40	193	52
.41	245	41	.62	144	69	1.23	82	123	.65	165	61	.65	155	65	1.05	73	136	.65	148	67
.65	186	54	.83	115	88	1.52	68	147	.96	113	89	.96	109	92	1.52	55	182	.96	110	91
.96	137	73	1.23	77	130	2.29	48	210	1.28	83	121	1.28	92	109	3.00	32	317	1.28	86	116
1.28	115	87	1.64	56	179	3.00	37	271	1.91	67	149	1.91	71	142				1.91	70	142
1.64	100	100	2.44	47	212				2.22	62	161	2.84	61	165				2.22	66	151
2.44	65	154	2.84	40	248				3.00	59	171							2.84	60	166
2.84	57	176																		
Per cent. Na_2SO_4			Per cent. Na_2SO_4			Per cent. Na_2SO_4			Per cent. Na_2SO_4			Per cent. Na_2SO_4			Per cent. Na_2SO_4			Per cent. Na_2SO_4		
0.10	878	11	0.10	723	14	0.09	829	12	0.08	796	13	0.08	927	11	0.09	765	13	0.08	396	25
.20	482	21	.20	448	22	.19	467	21	.23	426	23	.23	449	22	.19	471	21	.23	300	33
.40	374	27	.40	298	34	.38	271	37	.39	268	37	.39	302	33	.38	285	35	.39	248	40
.81	236	42	.81	164	61	.75	165	61	.71	174	58	.71	203	50	.75	157	64	.71	192	52
1.20	167	60	1.20	120	83	1.54	101	99	.94	144	70	.94	167	60	1.03	126	80	.94	166	60
1.60	131	76	1.60	105	96	2.95	74	136	1.14	123	81	1.25	128	79	1.54	91	111	1.25	149	67
2.27	104	96	2.27	81	123				1.85	97	103	1.85	100	100	2.95	60	166	1.85	129	78
2.96	84	118	2.96	75	134				2.46	91	110	3.00	72	138				2.46	112	89
									3.00	79	127							3.00	99	101
Per cent. Na_2CO_3			Per cent. Na_2CO_3			Per cent. Na_2CO_3			Per cent. Na_2O_3			Per cent. Na_2CO_3			Per cent. Na_2CO_3			Per cent. Na_2CO_3		
0.08	874	11	0.08	1322	8	0.07	1077	9	0.06	1060	9	0.06	1295	8	0.07	1368	7	0.06	503	20
.23	396	25	.23	797	13	.21	437	23	.17	624	16	.17	898	11	.42	328	31	.17	413	24
.38	282	36	.38	494	20	.42	224	45	.29	413	24	.29	576	17	.77	164	61	.29	368	27
.75	173	58	.75	269	37	.77	140	72	.58	227	44	.58	308	33	1.05	125	80	.58	312	32
1.10	139	73	1.10	196	51	1.54	92	109	.82	177	57	.82	202	50	1.54	90	112	.82	276	36
1.55	113	89	1.55	135	74	2.99	63	160	1.21	133	76	1.21	140	72	2.99	56	179	1.21	233	43
2.45	83	121	2.45	98	102				1.92	97	103	1.92	102	98				1.92	173	58
3.00	71	141	3.00	80	125				2.85	83	121	2.85	78	129				2.38	128	65
																		2.85	128	78

ing sodium chloride (NaCl) or sodium sulphate (Na_2SO_4) remained practically the same after ignition as before.

As further evidence of the effect of humus on the conductivity of the soil, fine quartz flour was treated with an alkaline solution of humus, and the humus precipitated by adding hydrochloric acid. After washing thoroughly, most of the humus was leached out, but that a coating of it was retained was shown by the charring of the quartz on ignition. The resistivity and conductivity of the pure quartz saturated with water and of the quartz after the addition of humus, and also with 0.23 per cent. Na_2CO_3, were as follows:

TABLE VII.

	Sat'd with H_2O		Sat'd with 0.23 per cent. Na_2CO_3	
	Resistivity	Conductivity ×10,000	Resistivity	Conductivity ×10,000
Quartz	3922	2.55	378	26.4
Quartz and Humus	15520	0.644	399	25.1

From this the greater conductance of the pure quartz saturated with water is shown. When 0.23 per cent. sodium carbonate is used the conductivity is also reduced with humus present. The value 25 is probably too high because of the difficulty of washing out completely the salt formed in adding hydrochloric acid to the alkaline solution of humus.

The various soils used in all the measurements were analyzed, and their percentage of organic matter, together with their conductivity ratios with carbonate (taken from Table VI) are given below:

Heavy clay	5.06	per	cent.	organic	matter	Ratio	0.52
Portsmouth sand	4.12	"	"	"	"	"	.68
Sandy loam	1.38	"	"	"	"	"	.95
Loam	1.12	"	"	"	"	"	.87
Clay	0.97	"	"	"	"	"	1.12

By reference to Table VI it will be seen that with sodium chloride and sodium sulphate no relation between the conductivity and the amount of organic matter is shown, but with sodium carbonate

there is a striking relation. The presence of the carbonate causes a lowering of conductivity, which is almost parallel to the increase of organic matter present.

These results may be of interest in their bearing on the subject of corrosion of iron and steel. Interesting cases of corrosion of pipe conduits have been cited by Gaines[8] and discussed by this Society. Prof. Burgess[9] in a presidential address before the Society discussed the electrochemical aspect of the corrosion of iron. W. H. Walker[10] has pointed out that all corrosion is probably electrolytic. If this is true, then it is of the highest importance to understand something of the influence of the soil upon the electric conductance of the current. This is plainly realized; Prof. Burgess, in the address mentioned, says: "Before accurate work can be done in treating this trouble, a large amount of data must be made available as to the electric conductivity of various earths, clays, gravels, etc. Iron carbide and uncombined carbon in the iron form active couples, as both are electro-negative to iron. Therefore corrosion will take place in the presence of an electrolyte." And it is the soil that furnishes the electrolyte.

Gaines, in the discussion of the corrosion of the Southern conduit of Rochester, says: "That soil influences played a *leading* part in the corrosion is obvious from the fact that the damage to the pipe was confined to ground conditions of a definite character, *i. e.*, soils in which was normally present an excessive amount of water." To show further the seriousness of this corrosion, Gaines declares: "No coating has yet been found that will withstand the severely corrosive influence of this character. Electrolysis occurs as a natural process in buried iron and steel pipe, when inadequately protected, provided the ground condition affords media for solution and conduction."

Whether the corrosion is caused by ordinary processes or by stray currents is of little consequence; the condition of the soil must be such as to afford these media, since corrosion in each case is essentially an electrolytic process.

[8] Trans., **13**, 66; Ibid., **14**, 165 (1908).

[9] Trans., **13**, 17 (1908).

[10] Jour. Am. Chem. Soc., **28**, 1,251. See also Cushman, Trans. Am. Electrochem. Soc., **14**, 159.

Summary.

From previous work we know that the condition of the soil has a marked influence on corrosion, and from a study of the soil conditions it has been observed that soil containing much water adds to the corrosive influence. Again, since corrosion is electrolytic, the solution in the soil—an electrolyte—facilitates corrosive action.

The measurements of soil resistivity show:

1. That in the dry condition, the soil offers a very high resistance to the passage of the current.

2. That at a depth of two feet or more for a given soil and area, the conductivity remains roughly constant.

3. That the conductivity of moist soil increases almost directly as the percentage of moisture increases, the amount of increase depending upon the type of soil.

4. That the conductivity of soils saturated with water increases directly as the amount of salt in solution increases.

5. That below saturation, the resistivity increases almost in proportion to the surface area of the soil; at saturation and beyond, the surface area does not exert so great an influence.

6. That sodium carbonate has an effect of greatly increasing the conductivity.

7. That humus decreases the conductivity of a soil.

8. Sandy soil will probably afford least electrolyte and clay soil most, due mostly to the state of physical division of the soil.

From the data given above it would be possible to calculate roughly the electrolysis (current passing) produced by a given potential difference between two points in the soil, the cross-section of the soil column involved being known. In such a calculation the texture, content of organic matter, water content and saturation point of the soil must be approximately known, as well as the content of soluble salts present in the soil solution. Such calculations, while rough, are of much practical value.

U. S. Dept. of Agriculture,
Bureau of Soils.

A paper presented by Dr. W. H. Walker at the Seventeenth General Meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 7, 1910, President L. H. Baekeland in the Chair.

THE SEPARATION OF OIL FROM CONDENSER WATER BY ELECTROLYSIS.

By H. M. Goodwin and Ridsdale Ellis.

The present paper contains the results of an investigation which was suggested by the English patent[10]* of Davis and Perrett, taken out in 1902, in which electrolysis was used as a means of effecting a separation of oil from condenser water. The description of the invention given in the patent specifications reads, in part, as follows:

"This invention consists in a method of, and apparatus for, effectually or wholly removing the oil or other impurities from condenser water and from other impure water (or emulsion), the said water being subjected to the influence of electricity, and then filtered or separated by centrifugal action or allowed to settle. The water to be purified is run into a vessel or vessels fitted with a number of suitable electrodes, by preference so formed or arranged that the water takes a circuitous path while subjected to the electric current. In order to render the current effectual there is added to the water at its inlet end as required a small and regulated quantity of ordinary clean water or of carbonate of soda or of potash dissolved in water.

"On passing the current through the water in the vessel the small particles of oil become detached or separated and become entangled with the detached minute particles of iron or other metal used for electrodes. When the oily particles have thus become detached they are easily removed by filtration or settling, so the water becomes pure and suitable for use as feed water.

"Analysis has shown that the oily particles are not oxidized or decomposed to any appreciable degree, and the oil can be recovered in the usual known manner from the scum that forms

* Numbers refer to bibliography at end of article.

on the surface of the water in the vessel or from the precipitate on the filter-cloths or in the settling tanks.

"In one practical example treating 2,000 gallons of very oily feed-water per hour we have found that current of about 15 amperes as a minimum at 150 volts thoroughly separates the oily parts from the water, and that these oily parts are subsequently wholly removed by downward filtration in a filter composed of coarse and fine sand. A large excess of current has been found to have no detrimental effect except a tendency to choke the filter by the needless excess of iron dissolved in the water."

From this description it is evident that the effect of the current is to so modify the character of the emulsion that the oil particles may be readily separated from the water by subsequent filtration. The process differs from other electrical methods which have been devised for the purification of ordinary water (not oily feed-water), in that an electrolyte is here added to give conductivity to the water. In most other cases the impurities in the water constitute the electrolyte, and the flocculant precipitate formed from aluminum or iron electrodes acts as clarifying agent. Of the other methods employed for the separation of oil from water may be mentioned the following:

1st. Gravity and mechanical separation as by a baffle-plate separator, which Carty[8] has shown will separate 75 percent of the oil fed to the cylinder of an engine.

2d. Addition of de-emulsifyers which destroy the film on the surface of oil particles, thus permitting them to coalesce.

3d. Filtration through various media.

In view of the intimate relation between emulsions and colloidal suspensions, it seemed to us of some interest to investigate the *rôle* played in the electric current, iron electrodes, and added electrolyte in the process of de-emulsification described above. During the progress of the investigation attention was also directed to a number of interesting related phenomena, such as the velocity of migration of the particles under various conditions. In the present paper, however, only a brief description and remumé of the principal experiments will be presented.

At the end of the paper is appended a bibliography which, it is believed, may prove of value to others who may undertake

work in this field. Altho no attempt has been made to ensure its completeness, it is believed to contain references to all of the more important articles relating to the subject under consideration.

GENERAL PROPERTIES OF EMULSIONS.

When pure oil is violently agitated with pure water no permanent emulsion is produced, for, if the mixture be allowed to stand, a complete separation of the two constituents takes place. The minute oil globules gradually rise, owing to their lesser specific gravity, and coalesce as they come into contact with one another. If, however, a small amount of emulsifying agent be present a portion of the oil will be permanently emulsified, *i. e.*, distributed through the water in a state so minutely divided that it cannot be separated from the medium by gravity or ordinary filtration. The *rôle* played by the emulsifier is to produce a film of solid matter over the oil globules so that coalescence on contact is prevented. The more common emulsifiers are such organic substances as soap, gums, proteids, and also certain colloids, such as ferric-hydrate. Ramsden[43] has shown that exceedingly small amounts of proteid matter are sufficient to effect emulsification. Electrolytes as a class do not act as emulsifiers, altho sodium carbonate or hydroxide will emulsify oils of fatty acids, owing to the formation of soap films.

Certain solid substances, like lime and clay, also act as partial emulsifiers, forming so-called quasi-emulsions. In this case the substance is retained in suspension by association with the minute solid particles rather than being completely enveloped by a solid film. The emulsifying power of solids depends very largely on the minuteness of the particles.

No definite magnitude can be assigned to particles forming permanent emulsions, but generally speaking they are sufficiently large to be visible under the microscope. Their size, therefore, distinguishes them from colloidal suspensions and the still smaller particles forming true colloidal solutions. Altho colloidal molecules are believed to be large, as indicated by their molecular weight, small osmotic pressure, rate of diffusion, etc., they are still so small as to be beyond the resolution of the best microscopes.

Colloids and emulsions possess the common property of migrating under the influences of a potential gradient, and are, therefore, electrically charged. Two distinct hypotheses have been proposed to account for the existence of the charge associated with them, which is usually negative in character, as shown by the direction of migration of the particles to the anode. The first hypothesis is due to Coehn[9] who states the general proposition that a difference of potential is always produced at the junction of two dissimilar media when brought into contact, that one assuming a positive charge which possesses the higher dielectric constant. This readily explains why water with its abnormally high dielectric constant of 80 is positively charged with respect to almost all particles suspended in it. The positive charge observed on such substances as colloidal ferric-hydrate seems an exception to this rule.

The second hypothesis assumes the charges to result from association or absorption of negative or positive ions with the colloidal or emulsified particles or an ionization of the colloidal molecules themselves. (See Noyes,[30] page 99.) It is not our present purpose to attempt to decide the relative merits of these two hypotheses. The fact that the emulsified particles are electrically charged, and that it is this charge which undoubtedly is instrumental in preventing them from separating under the influence of gravity from the medium containing them, is the important thing to be here recognized.

PREPARATION OF EMULSIONS.

As condenser water from a steam engine contains numerous unknown impurities, the emulsions used in the following experiments were all prepared from distilled water and Underhay's Premium Valve Cylinder Oil. The oil used gave the following tests:

1. Flash point (closed) ..... 282° C.
   " " (open) .....565° F., 296° C.
2. Fire test..... above 605° F., 318° C.
3. Viscosity on Doolittle's torsion viscosimeter = 76 (grams of sugar).
4. Specific gravity 0.896

The purity of the oil and the water was such that an emulsion of sufficient concentration could not be obtained by any method of mechanical agitation, or by passing superheated steam at 200° C. through the oil and allowing it to condense. At best only a very slightly turbid emulsion could be thus obtained. To approximate the conditions of condenser water, it was, therefore, decided to add an emulsifier in the form of wool-grease. Two percent of this substance was added to 25 c.c. of the oil and the mixture agitated at 100° C. in a wide-neck bottle containing 1,000 c.c. of water. After an hour of vigorous stirring the excess of oil was allowed to rise to the top of the liquid. After standing over night the emulsion was siphoned off and filtered through filter paper. In this way a fairly permanent stock emulsion was obtained. It appeared as a slightly brown turbid liquid. Examined under the microscope the globules of the emulsion were found to vary in diameter from 0.0006 cm. to 0.00006 cm., the average being about 0.0003 cm. The smallest globules exhibited a very slight Brownian movement.

To determine the amount of oil in these emulsions a modification of a method devised by Carty was employed—namely, extraction of the oil by ether.

To 300 c.c. of emulsion, 10 c.c. of concentrated hydrochloric acid were added to de-emulsify it; 50 c.c. of ether were then added and the whole shaken up in a separating funnel and allowed to stand for several hours. The ether was then separated, placed in a weighed flash, and a current of air drawn through the latter to evaporate the ether. The flask was finally placed in a hot-water bottle to evaporate the small amount of water unavoidably present, after which it was weighed again and the weight of oil in 300 c.c. of emulsion obtained. Analysis showed that emulsions prepared as described above contained on the average 0.1283 gm. of oil per 100 c.c., and will be referred to as standard or stock emulsions.

To determine the amount of oil removed from this stock emulsion by any procedure, a portion of the original emulsion was diluted with pure water until its turbidity became equal to that of the sample under investigation. The turbidity of fairly concentrated emulsions was determined by placing at least 100 c.c. of the emulsions in Ehrlenmeyer flasks and comparing them by

transmitted light. The precision was about 7 percent. The limiting dilution at which turbidity could still be detected corresponded to a concentration of one part of oil to 1,000,000 parts of water.

For dilute emulsions it was found much more accurate to estimate turbidities by reflected rather than by transmitted light, for which purpose a modified form of Richards' nephelometer[14] was used. Soap solutions 0.05%, 0.005% and 0.0005%, respectively, were used as standards of reference. These were standardized by reference to emulsions of known oil contents. The precision of this method was found to be about 4%.

EXPERIMENTAL RESULTS.

The experiments on electrolysis were carried out in cells of the type shown in Fig. 1 and 2, the anode and cathode side of the

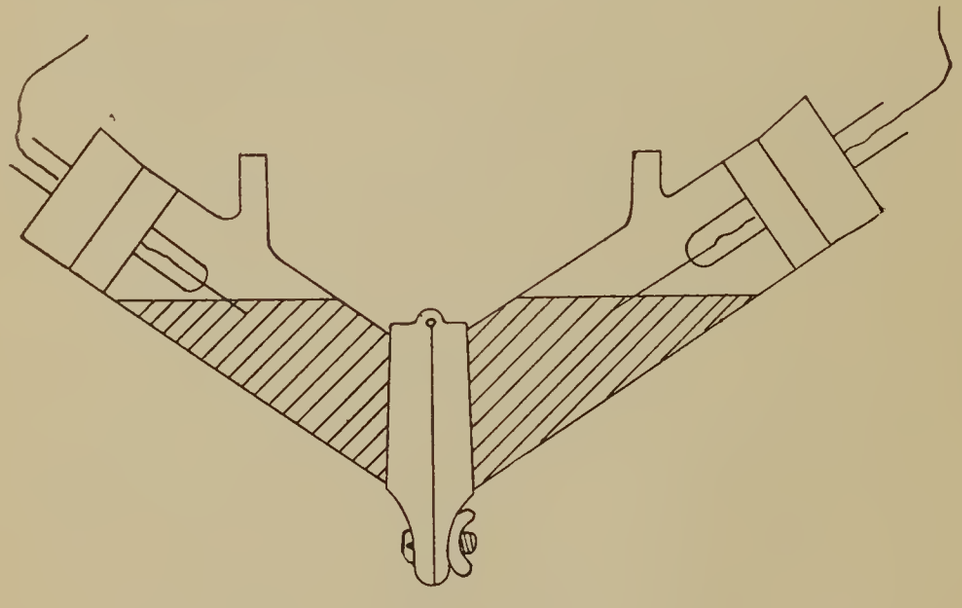


FIG. 1.

U-tube being separated by a filter paper partition. The anode and cathode portions could thus be readily separated after electrolysis and investigated. In certain experiments the direction and velocity of the particles under the action of an applied electromotive force was studied under a microscope. For this purpose two fine platinum or iron wire electrodes were fastened across a microscope slide, parallel to each other and 1.42 cm. apart, the emulsion poured between them and covered by a second slide which rested on the wires. The distance traversed by the particles was read off by means of a calibrated eye-piece micrometer.

1. *Effect of electrolytes on de-emulsification, without current.*

Solutions consisting of 90 c.c of the standard emulsion plus 10 c.c. normal sodium hydrate, sodium carbonate and acid sodium carbonate, respectively, were vigorously shaken, allowed to stand for an hour and filtered. No appreciable de-emulsification could be detected in the filtrate. The presence of either of these electro-

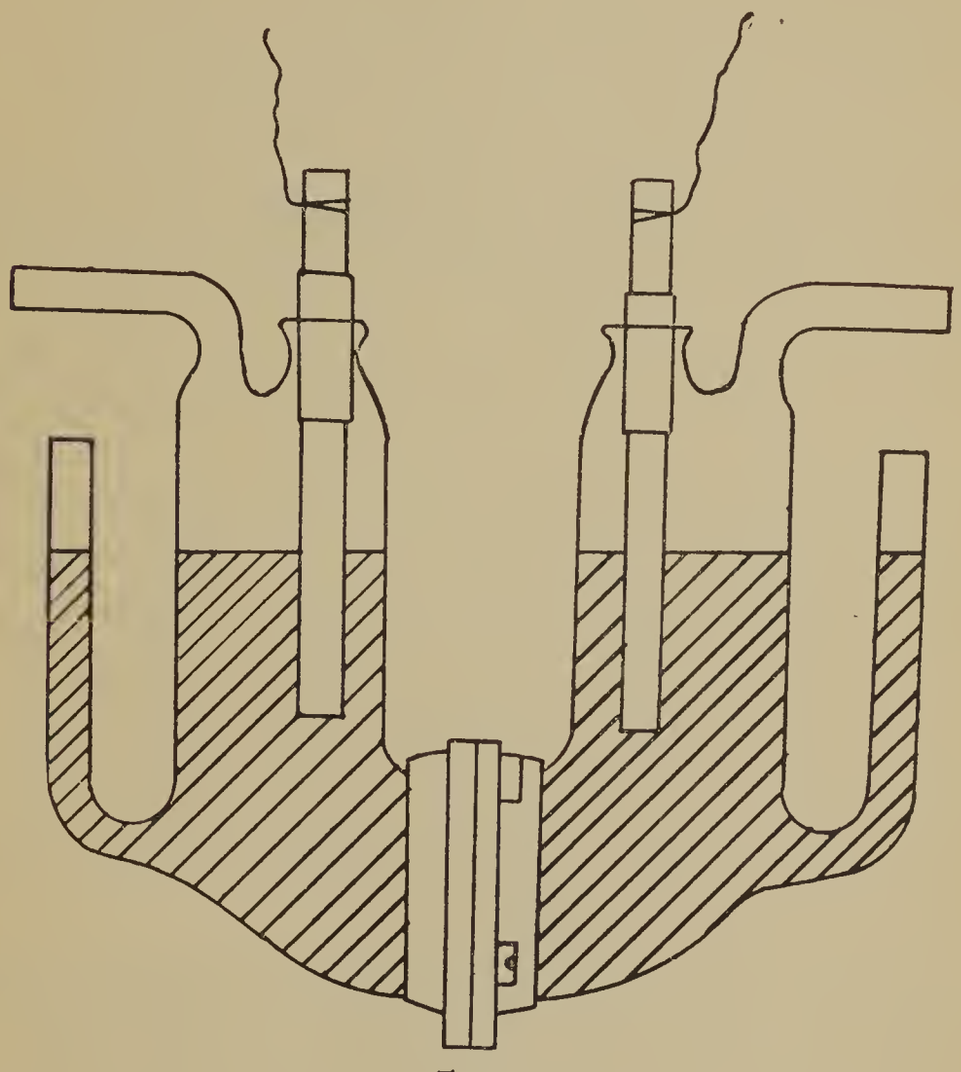


FIG. 2.

lytes is, therefore, not sufficient to cause by itself a separation of the oil from the solution.

2. *Effect of electric current on the emulsion in the absence of added electrolytes.*

The cell was first filled with the standard emulsion and platinum electrodes inserted in the anode and cathode compartment. A potential of 110 volts was then applied for one hour. Owing to the very low conductance of the emulsion a current of only a

few milli-amperes was observed. The particles of oil migrated, nevertheless, as if negatively charged, *i. e.*, to the anode, the cathode liquid becoming thereby clearer. This was confirmed by observation under the microscope. No de-emulsification was observed at the anode. On filtering separately the anode and cathode portions, the former appeared slightly turbid, the latter only in comparison with pure water. The cathode liquor was found to be neutral; the anode liquid slightly acid.

3. *Electrolysis with sodium carbonate and platinum electrodes.*

The above experiment was repeated with emulsion containing 0.01-normal sodium carbonate. The results were essentially the same, the conductance of the mixture and hence the current being considerably greater, however.

4. *Electrolysis with sodium carbonate and iron electrodes.*

The experiments were next repeated, using iron electrodes, as in the Davis patent, the emulsion being 0.004-normal with respect to sodium carbonate. A potential of 115 volts was applied. Hydrogen was liberated at the cathode; no gas, but a greenish precipitate was formed at the anode, which fell through the liquid to the bottom of the cell. The anode liquid when filtered after electrolysis appeared perfectly clear by transmitted light. The product formed at the anode had thus accomplished the de-emulsification of the oil to such an extent that it could be practically completely removed by filtration.

The experiment was repeated with a 0.001-normal sodium carbonate solution, taking every precaution to remove all oxygen from the solution before electrolysis and to exclude it during the experiment. An exceedingly fine light-green precipitate formed in the solution, which retained the oil when the solution was filtered. The filtrate showed a faint greenish turbidity in the nephelometer, but no oil globules could be detected under the microscope. It is possible that this green color and turbidity may be due to some colloidal ferrous hydrate remaining in the liquid, altho this is by no means proved.

The phenomena described in the process being thus confirmed, we next endeavored to determine the manner in which the process of de-emulsification took place. When dilute neutral sodium

carbonate is electrolyzed between iron electrodes, the process at the cathode is simple; hydrogen is liberated and the solution becomes alkaline. At the anode, on the other hand, the several possible secondary reactions make the process more complex. The greenish precipitate formed is probably basic ferrous carbonate. Owing to the hydrolysis of sodium carbonate in dilute solution and to the possibility of carbonic acid dissociating partially into $\overset{+}{H}$ and $H\overset{-}{C}O_3$ ions, it follows that in the neighborhood of the anode there are probably present some $\overset{--}{C}O_3$, $H\overset{-}{C}O_3$ and $\overset{-}{O}H$ ions, all ready to give up their negative charge under a sufficiently high voltage. With the voltage applied in the experiments all of these anions may be assumed to become discharged, and hence the following reactions with the soluble iron anode may take place:

$$Fe + \overset{--}{C}O_3 + 2(+) = Fe\,CO_3$$

$$Fe + 2H\overset{-}{C}O_3 + 2(+) = Fe\,H_2(CO_3)_2$$

$$Fe + 2\overset{-}{O}H + 2(+) = Fe\,(OH)_2.$$

Of these compounds, ferrous hydrate is very insoluble (solubility one part in 150,000 water), and hence owing to the presence of $\overset{-}{O}H$ ions arising from hydrolysis*, it seems probable that any ferrous carbonate or bicarbonate formed will be precipitated as a basic ferrous salt—the pale-green precipitate observed. This, if exposed to the air, will, of course, be gradually oxidized to the ferric form. It is also conceivable that a portion of the iron may dissolve in the form of a colloidal solution. Which of the compounds formed is probably effective in de-emulsifying the solution will now be considered.

In the first place, a microscopic examination of the coagula was made and the process of de-emulsification observed under the microscope. The former examination showed the separate oil globules to be entangled in the meshes of the precipitate and not

*Also from the cathode liquid if anode and cathode portions are allowed to mix.

coalesced with each other. When the electrolysis was carried out between iron wire electrodes on a microscopic slide, it was seen that the oil particles moved quite rapidly toward the anode, and became entangled in the green film of precipitate there produced. They were repelled from the cathode. It was further shown that contact with the electrodes was not in any way an essential part of the process of de-emulsification, or, in fact, is the electric current of itself necessary, for by adding to the emulsion a portion of the anode liquid containing basic iron precipitate, it was found that the oil particles were rendered capable of filtration by associating themselves with the precipitate. In fact, the emulsion could be completely clarified by shaking it up with a sufficient amount of basic precipitate. Since, however, it is well known that positive and negative colloids precipitate each other when brought into contact, the above experiment does not conclusively prove that colloidal de-emulsification may not also play a part in the process here considered, provided some iron is dissolved in the colloidal form. To test that, the following experiments were carried out.

5. *Effect of colloidal ferrous oxide on the emulsion.*

Colloidal ferrous hydrate was prepared as follows:[53] Ferrous bicarbonate, $FeH_2(CO_3)_2$, was first made by electrolyzing a saturated solution of carbon dioxide between iron electrodes. Carbon dioxide was continually passed through the solution and air excluded by covering the surface with oil. The bicarbonate was syphoned off. The colloidal ferrous oxide (or hydrated oxide) solution was then made by dropping the bicarbonate solution into boiling water. On mixing equal volumes of this clear blackish solution and the standard emulsion no coagulation was produced, even after twelve hours. Colloidal ferrous oxide does not, therefore, act as a de-emulsifier.

6. *Effect of colloidal ferric hydrate on the emulsion.*

As colloidal ferric hydrate is known to be a positively charged colloid, it was anticipated that it would probably tend to de-emulsify the negatively charged oil globules. The colloidal ferric hydrate was made according to directions given by Graham[19] by adding a small amount of ammonium carbonate to a very

dilute solution of ferric chloride. The solution was dialysed for a fortnight, the water being changed every day. The solution was analyzed and found to contain 0.18 gram of $Fe(OH)_3$ per liter. This served in the following experiments as our *standard* solution.

The addition of 5 c.c. of this solution to 95 c.c. emulsion caused complete coagulation. On filtering immediately, a clear filtrate was obtained. The coagulated particles at first were not large enough to be visible to the naked eye. though they rapidly became so on standing. If left for some hours all of the precipitate settled out and a clear liquid remained. The particles examined under a microscope were found to consist of a large number of oil globules held together by a transparent membrane or jelly. The removal of the oil particles by filtration, after the addition of the ferric hydrate, is due to the association with the hydrate of separate oil globules and not to the coalescence of small globules into larger ones.

To determine, if possible, the mechanism of the coagulation, a drop of emulsion and a drop of colloidal ferric hydrate were brought together side by side on a microscope slide and the junction observed under a microscope. Some of the oil globules had been coalesced by the act of placing the drops together on the slide, but no movement of the oil globules could be detected. Any motion of the colloid could not, of course, be detected as the solution was perfectly transparent. When a potential was impressed it was noticed that the majority of the globules at the boundary migrated into the ferric hydrate, *i. e.,* towards the anode, while a few migrated in the opposite direction. When two globules migrating in opposite directions met, the two adhered together, and did not migrate in either direction. This is analogous to the "reverse movement" of colloids observed by Whitney and Blake[54], Picton and Linder[38] and others.

It was further observed that the coagula obtained by shaking the emulsion with an excess of ferric hydrate, migrate to the anode and not to the cathode, as does the colloid itself.

The amount of ferric hydrate required to coagulate the oil was next determined. To 40 c.c. of emulsion varying amounts of colloidal ferric hydrate solution were added. In each case the

solution was diluted with distilled water to 50 c.c. The solutions were allowed to stand half an hour and were then filtered.

No. of Solution	Mixture			Filtrate
	Standard Emulsion		Standard $Fe(OH)_3$	
1	40 c.c.	+	10 c.c.	Very slightly turbid.
2	40 "	+	5 "	Perfectly clear.
3	40 "	+	2 "	Very slightly turbid.
4	40 "	+	1 "	Perfectly clear.
			Standard $Fe(OH)_3$ diluted 1 to 10	
5	40 c.c.	+	10 c.c.	91 percent of the oil removed.
6	40 "	+	5 "	No oil removed.
7	40 "	+	2 "	No oil removed.
8	40 "	+	1 "	No oil removed.

From this it appears that no coagulation occurs unless the concentration of the colloidal hydrate reaches a minimum value, between that corresponding to solution 5 and 6.

7. *Effect of sodium carbonate on colloidal ferric hydrate.*

Since any colloidal ferric hydrate which might be formed in the anode compartment in the electrolysis of a carbonate solution would be in the presence of this salt, we next investigated the coagulating power of a 0.001-normal solution of sodium carbonate on independently prepared colloidal ferric hydrate solutions of varying strengths. After thoroughly mixing the solutions they were allowed to stand one-half hour and then filtered and the filtrate examined in the nephelometer.

No.	Solutions					Results
	0.01—Na_2CO_3		Colloidal Ferric Hydrate		H_2O	
1	10 c.c.	+	20 c.c.	+	70 c.c.	Coagulated.
2	10 "	+	10 "	+	80 "	Coagulated.
3	10 "	+	5 "	+	85 "	Very slightly coagulated.
4	10 "	+	2 "	+	88 "	Coagulation doubtful.

A comparison of these results with those in the preceding experiment shows that a 0.001-normal solution of sodium carbonate will coagulate solutions of ferric hydrate which on their part are so

diluted as to have no de-emulsifying action on the oil. Hence it seems that even if colloidal ferric hydrate is formed during any part of the process in the electrolysis of a sodium carbonate solution, as dilute as even 0.001-normal, it will become coagulated by the electrolyte before reaching a sufficient concentration to itself de-emulsify the oil.

8. *Efficiency of various media as filtrates.*

We next investigated the efficiency of various precipitates when used as filters, to separate oil from the emulsion. The results are given below:

$Fe(OH)_3$	Perfectly clear filtrate.
$Al(OH)_3$	(Clear by transmitted light, but not necessarily so by nephelometer).
$Cr(OH)_4$	
$Ca(OH)_2$	
FeO	
Red Ochre	
$BaCO_3$	
Siderite	
Limonite	
Bone Black	
Spongy Iron	
Fine Ground Coke	
Asbestos, ½ inch thick	
$BaSO_4$	No oil removed.
$PbCl_2$	Little oil "
Cotton Wool	No oil "
Glass Wool	" " "

It is, of course, evident that where filtration takes place through a sufficiently finely divided layer of particles all the oil globules will be removed, merely for mechanical, if for no other reason.

To test whether the oil globules were filtered out because the interstices of the filtering medium were too small for the oil to pass through, several of the substances used as filters were shaken up with emulsion and then examined microscopically and photomicrographs taken to determine if the oil globules adhered to the particle of solid. With bone black, red-ochre, limonite and other substances the oil globules could be seen adhering to the solid matter, while with barium sulphate, lead chloride and others no such agglomeration took place.

It was found that the coagula obtained by electrolysis using iron electrodes, by coagulation with colloidal ferric hydroxide, and

by the precipitation of a very small amount of basic ferrous sulphate in the emulsion, were all similar.

These three substances are, moreover, good emulsifiers.[42] To determine if emulsifiers in general coagulate the oil and non-emulsifiers do not, precipitates of those substances which do not emulsify were formed in the emulsion and the results photographed. The substances investigated in this way were aluminum silicate, barium sulphate and lead chloride. Aluminum sulphate forms a gelatinous precipitate, but even when the smallest possible amount of precipitate is formed in the solution there is no sign of coagulation of the oil globules. A number of oil globules are mechanically enclosed, however, as can be seen from the photographs. With barium sulphate or lead chloride the crystals are not formed on the surface of the oil globules. If shaken with red-ochre or hydrated ferric oxide, which is a good emulsifier,[37] the majority of the oil globules become more or less coated with particles of red-ochre. The photomicrographs of barium sulphate and lead chloride show no sign of any attraction between the precipitated particles and the oil globules.

As to the efficiency of oil separation in the Davis process, the statement is made that a test in which 15 amperes was used (at a voltage of 150 across the terminals of the apparatus) completely separated the oil from "very oily feed water" flowing at the rate of 2,000 gallons per hour through the apparatus. No figures are given as to the composition of the "very oily feed water" used, but, assuming one part of oil in 60,000 parts of water (*i. e.*, that found by analysis of a sample of condenser water at the Institute), the quantity of oil contained in 2,000 gallons would be, approximately, 130 grams. If the iron anode goes into solution primarily as ferrous iron, 15 ampere hours would dissolve as a maximum 15.6 grams of iron, which, subsequently oxidized to ferric hydrate, corresponds to 30 grams. Hence, one gram of ferric hydrate appears to be sufficient to de-emulsify at least four grams of oil. Our experiment on the de-emulsification of oil by ferric hydrate in the colloidal form indicates (solution 4) that one gram of the colloidal hydrate (calculated as $Fe(OH)_3$) will separate about 28 grams of oil, or nearly seven times as much from an emulsion 7.7 times as concentrated.

The efficiency of separation of other media was only approxi-

mately determined. The amount of oil left after filtering the standard emulsion through half an inch of finely ground coke was found to be 0.00485 gm. per liter; hence, 96% of the oil was removed. Filtration in this case was not aided by suction. When suction was used with the same thickness of coke the efficiency naturally fell off very materially.

The efficiency of filtration through red-ochre was also tried. In this case a 1/16-inch layer of fine red-ochre was used (through 100 mesh) and suction filtration employed. The filtrate in this case analysed 0.00074 gm. per liter, showing an efficiency of 99.5%. The slow rate of filtration is the main objection to the use of red-ochre in practice. In the above experiment the rate of filtration was 600 c.c. in 10 minutes through a filter 10 cm. in diameter; *i. e.*, 0.76 c.c. per sq. cm. per minute. In the case of red-ochre the efficiency of filtration is decreased if the rate of filtration is increased. If the rate of filtration is approximately doubled by increasing the suction, the content of oil in the filtrate was increased to 0.00187 gm. per liter. As the filtrate, viewed in the nepthelometer, was decidedly red, a considerable amount of the increase in suspended matter is undoubtedly red-ochre and not oil.

When the standard emulsion was distilled, a part of the oil passed over with the steam, leaving behind a residue of oil, fatty acids and other organic matter from the wool-grease. These separated out from the solution as fragments of films—the "mechanical surface aggregates" of Ramsden. Water purified by filtration through red-ochre when evaporated nearly to dryness, showed no trace of formation of such films.

SUMMARY.

Experiments are described the purpose of which was to add to our knowledge of the nature of the process involved in the separation of oil from oil emulsions, such as occur in condenser water, particularly when the emulsions are rendered conducting by the addition of sodium carbonate and subjected to the action of an electric current between iron electrodes.

The results established and presented in this communication are the following:

(a) The oil particles in the emulsions investigated vary in diameter from about 0.0006 cm. to 0.00006 cm., and are negatively charged, as shown by their migration to the anode under the influence of a potential gradient.

(b) The addition of dilute solutions of sodium carbonate does not produce de-emulsification.

(c) Partial de-emulsification of oil (about 50 to 60 percent) is produced by the action of an electric current using platinum electrodes; this is probably due to the "reverse motion" noticed by Hardy and others.

(d) Complete de-emulsification results from using iron electrodes, as in the Davis process.

(e) The essential part of the process is the removal of the oil, by the basic ferrous carbonate formed at the anode coming into contact with the oil particles as they migrate to the anode; mechanical agitation of the emulsion with this precipitate serves, however, equally well to remove the oil.

(f) A microscopic and photomicrographic study of the phenomena shows the oil to be held in the meshes of precipitate.

(g) Colloidal ferrous oxide does not produce de-emulsification of the oil.

(h) Colloidal ferric hydrate, a positive colloid, if present in sufficient concentration effects complete de-emulsification.

(i) Sodium carbonate coagulates colloidal ferric hydrate at a concentration less than that necessary for it to de-emulsify the oil, and hence, if colloidal ferric hydrate be formed during the process of electrolysis, it will be coagulated by the carbonate present before it can become effective as de-emulsifying agent. Therefore, colloidal ferric hydrate plays no essential *rôle* in the process. It seems that the chief agent in de-emulsification is the freshly formed basic ferrous carbonate resulting from electrolysis. The migration of the oil to the anode assists, however, in a measure, in the association of the two substances. The subsequent oxidization to ferric salts is unessential to the process, altho precipitated ferric hydrate was shown to act as a good filter.

(j) The efficiency of a number of precipitates used as filters for separating oil were investigated. Ferric hydrate and red-ochre were found to be among the best.

(k) From a photomicrographic study of coagula produced

by precipitating emulsifiers and non-emulsifiers in oil emulsions, it appears that in general those substances, such as basic ferrous sulphate, lime and alumina, which act as emulsifiers may also serve to de-emulsify a mixture. Precipitation of the positively charged particles takes place on the negatively charged oil globules as nuclei in a manner analogous, perhaps, to the precipitation of water vapor on negative electrons. With non-emulsifiers, such as barium sulphate and lead chloride, the precipitation does not occur on the globules, but entirely distinct from them.

Electrochemical Laboratory,
Massachusetts Institute of Technology.

BIBLIOGRAPHY.

1. *Archbutt, L., and Deely, R. M.*—Lubrication and lubricants.
2. *Bemmeln, J. M.*—Über das Kolloid des Eisenoxyds, Rec. Trav. chim. Pays Bas *7,* 114 (1888).
3. *Biltz, W.*—Über die gegenseitige Beeinflussung colloilaal gelöster Stoffe. Ber. d. Chem. Ges. *37,* 1095 (1904).
4. *Bliss, W. J. A.*—Die Kräfte welche anschiedend zwischen kleinen festen Teilchen herrschen die vollständig in Flüssigkeiten eingetaucht sind. Chem. Centralblatt. II, 340 (1895). Phys. Rev. *2,* 241 and 373 (1895).
5. *Bodlander, G.*—Versuche über Suspensionen. Jahrb. f. Mineral II, 147 (1893). Jahr. Forts. d. Chemie. 241 (1893).
6. *Boucher, P. J.*—Electrolytic water purifier. U. S. Patent 760,302, May 17, 1904.
7. *Brucke, E.*—Sitzungsber. d. Wiener Akad. *79,* III, 267 (1867).
8. *Carty, F. J. and M. W.*—An investigation of oil separators. M. E. Theses, Mass. Inst. Technology (1904).
9. *Coehn, A.*—Über ein Gesetz der Electricitätserregung. Ann. Phys. [3] *64,* 217-232 (1898).
10. *Davis, H. T., and Perrett, E.*—New and improved methods for separating oily and other impurities from water. Eng. Pat. No. 10,874, 1902.
11. *Dehne, A. L. G.*—Process for separation of oils and fats from water. Eng. Pat. 21,131, 1894. J. Soc. Chem. Ind. *14,* 1085 (1895).
12. *Dougherty, W.*—Feed-water purifier and filter. U. S. Pat. 769,792, Sept. 13, 1904.
13. *Dunstan, W. R., Dickinson, H. A., and Goulding, E.*—The rusting of iron. J. Chem. Soc. (Trans.) *87,* 1548-74 (1905).
14. *Frankland, P. F.*—New aspects of filtration and other methods of water purification. J. Soc. Chem. Ind. *4,* 698 (1885).
15. *Frazier, G. W.*—Electrolytic water purifier. U. S. Pat. 741,322, Oct. 13, 1903.
16. *Gad, E.*—Arch. f. Anat. u. Phys. 181-205 (1878).
17. *Gameson, C. H.*—Oil separator. U. S. Pat. No. 818,431, Nov. 28, 1904.

18. *Goodwin, H. M.*—On the hydrolysis of ferric chloride. Technology Quarterly *9*, No. 4, Dec., 1896; Zeit. für Phys. Chem. (1896).
19. *Graham.*—Anwendung der Diffusion der Flüssigkeiten zur Analyse. Liebig's Ann, *121*, 46 (1862). Phil. Trans. p. 183 (1861).
20. *Hall, V. J.*—A study of ferric hydroxide in precipitation. Am. Chem. Journal *19*, 512 (1897).
21. *Hardy, W. B.*—Coagulation and migration of Globulin. J. Physiol. *29*, 26 (1903).
22. *Hardy, W. B.*—Coagulation of colloids by electricity. J. Physiol. *24*, 292 (1899).
23. *Just, G.*—Kinetische Untersuchung der Autoxudation des in Wasser gelösten Ferrobicarbonats. Ber. Chem. Gessell, *40*, 3695 (1907).
24. *Lamb, H.*—Über die Theorie der elekr. Endosmose und andere verwandte Phänomene, und über die Existenz eines Gleitungsefficienten für eine Flüssigkeit in contact mit einem festen Körper. Wied, Beibl. *12*, *272*. Phil. Mag. [5] *25*, 52-70 (1888).
25. *Mayer, A., and Salles, E.*—Über den elektrischen Transport der anorganische Kolloide. Z. Chem. Ind. Colloide, *3*, 138. Compt. Rend. *146*, 826 (1908).
26. *Miller, H. G.*—Oil separator. U. S. Pat. 832,616, Jan, 6, 1905.
27. *Mott, W. R.*—Valence and colloidal precipitation. Elch. Ind. *2*, 446.
28. *Müller, A.*—Allgemeine Chemie der Kolloide.
29. *Müller, A.*—Bibliography der Kolloide.
30. *Noyes, A. A.*—Preparation and properties of colloidal mixtures. J. Am. Chem. Soc. *27*, 85 (1905).
31. *Ober, J. E.*—Coagulation of colloidal solutions. Mass. Inst. Technology. Theses (Chem. Dept.) *2*, (1901).
32. *Ober, J. E.*—Precipitation of colloids by electrolytes. Mass. Inst. Tech. Theses for M. S. (Chem. Dept.) 1902.
33. *Ordway, D. L.*—Coagulation of colloidal metal solutions. Mass. Inst. Tech. Theses (Chem. Dept.) *2* (1901).
34. *Peabody and Miller.*—Steam boilers.
35. *Perrin, J.*—Conditions qui determinent le sens et la grandeur de l'electrisation par contact. Compt, Rend. *136*, 1441 and 1388 (1903).
36. *Perrin, J.*—Mecanisme de l'electrisation de contact et solutions colloides. J. Chim. Phys. *3*, 50-110 (1905).
37. *Pickering, S. U.*—Emulsions. J. Chem. Soc. *91*, 2001 (1907). Proc. Chem. Soc. *23*, 256 (1907).
38. *Picton, H., and Linder, E. S.*—Solution and pseudo-solution. Part I. J. Chem. Soc. *61*, 148 (1892).
39. *Picton, H., and Linder, E. S.*—Solution and pseudo-solution. Part III. The electrical convection of certain dissolved substances. J. Chem. Soc. (Trans.) *71*, 568 (1897).
40. *Picton, H., and Linder, E. S.*—Solution and pseudo-solution. Part IV. J. Chem. Soc. (Trans.) *87*, 1906 (1905).
41. *Quincke, G.*—Über die Fortführung materieller Theilchen durch stromende Electricität. Ann. Phys. [2] *113*, 513-598 (1861).
42. *Quincke, G.*—Über Emulsionsbildung und den Einfluss der Galle bei der Verdauung. Pflugers Arch *19*, 129 (1879). Phil. Mag. [5] *7*, 301 (1879).
43. *Ramsden, W.*—Separation of solids in the surface-layers of solutions and suspensions. Proc. Roy. Soc. *72*, 156 (1903).
44. *Richards, T. W., and Wells, R. C.*—The nepthelometer, an instrument for detecting and estimating opalescent precipitates. Am. Chem. Journ. *31*, 235 (1904).
45. *Ruff, O.*—Über das Eisenoxyd und seine Hydrate. Ber. *34*, 3417 (1901).

46. *Schweikert, H.*—Über reinigung von Wasser mittels Eisenhydroxyd und ein Verfahren zur Herstellung einer geeigneten Lösung von kolloidalen Eisenhydroxyd ohne Dialyse. Z. Chem. Ind. Colloide, *1*, 248.
47. *Schweikert, H.*—Verfahren zur Herstellung einer zur Reinigung von Wasser im Grossbetriebe geeigneten Lösungen von Dialyse. D. R. P. Nr. 173,773, July, 1904. Z. Chem. Ind. Colloide *1*, 127.
48. *Smoluchowski.*—Theoretical considerations of the velocity of migration of colloids. Phys. Chem. Rev. *1*, 124; Bull. Acad. Sci. de Cracovie, 124 (1903).
49. *Watson, D. L.*—Electrolytic water purifier. U. S. Pat. 761,187, May, 1904.
50. *Wells, H. M., and Taggart, W. S.*—Cylinder oil and cylinder lubrication.
51. *Whetham, W. C. D.*—Die Koagulierende Wirkung von Elektrolyten. Z. Phys. Chem. *32*, 637 (1900); Phil. Mag [5] *48*, 474-77 (1899).
52. *Whetham, W. C. D.*—Theory of solutions.
53. *Whitney, W. R.*—The corrosion of iron. J. Am. Chem. Soc. *25*, 394 (1903).
54. *Whitney, W. R., and Blake, J. C.*—The migration of colloids. J. Am. Chem. Soc. *26*, 1339.
55. *Whitney, W. R., and Ober J. E.*—Über die Ausfällung von Kolloiden durch Elktrolyte. J. Am. Chem. Soc. *23*, 842-63 (1902).
56. *Whitney, W. R., anl Straw, A.*—Suspensions in dilute alkaline solutions. J. Am. Chem. Soc. *29*, 325 (1907).

DISCUSSION.

MR. CARL HERING: I have made a study of the migration of suspended particles in electrolytes due to the current, and have found that all materials have a definite direction, most of them traveling with the current, and a very few in the opposite direction. If I understand rightly, Dr. Goodwin says that alternating current may be used in his method, but if my observations are correct, it could not be used, as the particles would then not migrate.

DR. WILLIAM H. WALKER: In the paper he does not say what kind of current is used, but it must be direct current to produce the phenomenon.

DR. H. M. GOODWIN *(Communicated)*: As Dr. Walker pointed out, direct current only was used throughout this research. As an alternating potential gradient would evidently have no significance in connection with the experiments described, it seemed superfluous to make a specific statement that direct current only was used.

INDEX.

PAGE

Address, Presidential; Science and Industry—L. H. Baekeland..... 37
Allegheny Plate Glass Company, Glassmere, Pa..... 16
Alloys, Electrochemical Potential and Electrical Conductivity of Aluminium-Calcium—J. M. Breckenridge.....367
Alternating Current Conductors for Electric Furnaces, A Study in Heavy—K. C. Randall 139
Aluminium-Calcium Alloys, Electrochemical Potentials and Electrical Conductivity of—J. M. Breckenridge.....367
Amberg, R.—*Discussion*.....136
A New Electric Steel Furnace—A. L. Queneau.....131
A New Method for the Electrolytic Winning and Refining of Metals—E. M. Chance.....235
A New Process for the Treating of Cobalt-Nickel Ores—C. C. Cito...239
A New Radiation Pyrometer—C. E. Foster.....223
Annual Report of Board of Directors..... 24
Annual Report of the Secretary..... 25
Annual Report of the Treasurer..... 29
Anode, A Rotating Graphite—J. W. Turrentine.....303
A Rotating Graphite Anode—J. W. Turrentine.....303
A Study in Heavy Alternating Current Conductors for Electric Furnaces—K. C. Randall.....139
Baekeland, L. H.—Presidential Address; Science and Industry..... 37
Baekeland, L. H.—*Discussions*.....101, 326, 338 *et seq.*
Betts, A. G.—*Discussion*.....272
Brazing and Machine Company, Pittsburgh Reinforced..... 15
Breckenridge, J. M.—Electrochemical Potentials and Electrical Conductivity of Aluminium-Calcium Alloys.....367
Brown, J. W.—*Discussion*.....227 *et seq.*
Burgess, C. F.—*Discussion*.....337
Business Meeting of the Society..... 7
Calcium-Aluminium Alloys, Electrochemical Potentials and Electrical Conductivity of—J. M. Breckenridge.....367
Carnegie Steel Company: Homestead Works..... 20
Carnegie Steel Company: Isabella Furnaces..... 10
Cell, Some Characteristics of the Modern Dry—D. L. Ordway.....341
Cell, The Townsend—H. K. Richardson and R. L. Patterson.....311
Cell, The Whiting Electrolytic—J. Whiting.....327
Cement Company, Universal Portland..... 14

PAGE
Chance, E. M.—A New Method for the Electrolytic Winning and Refining of Metals....235
Characteristics of the Modern Dry Cell—D. L. Ordway....341
Cito, C. C.—A New Process for the Treating of Cobalt-Nickel Ores....239
Cobalt-Nickel Ores, A New Process for the Treating of—C. C. Cito...239
Comparison of Rapid Electro-Analytical Methods—1. The Determination of Copper—F. C. Frary, A. P. Peterson....295
Condenser Water by Electrolysis, The Separation of Oil from—H. M. Goodwin and R. Ellis....405
Conductivity and Electrolysis of Cuprous Chloride Solutions—M. deK. Thompson and E. R. Hamilton....287
Conductivity of Aluminium-Calcium Alloys, Electrochemical Potentials and Electrical—J. M. Breckenridge....367
Conductivity of Soils, The Effect of Moisture and of Solutions Upon the Electric—R. O. E. Davis....391
Conductors for Electric Furnaces, A Study in Heavy Alternating Current—K. C. Randall....139
Conservation and Utilization of Natural Sources of Power—J. H. Finney 55
Constants of Materials for Furnace Electrodes, Determinations of—Carl Hering 151
Copper, The Determination of—F. C. Frary and A. P. Peterson....295
Crabtree, F.—Possibilities of Cheap Power in the Pittsburgh District... 95
Crucible Steel Co. of America: Park Works.... 10
Cuprous Chloride Solutions, The Conductivity and Electrolysis of—M. de K. Thompson and E. R. Hamilton....287
Davis, R. O. E.—The Effect of Moisture and of Solutions Upon the Electrical Conductivity of Soils....391
Determinations of the Constants of Materials for Furnace Electrodes—Carl Hering 151
Directors, Annual Report of the Board of.... 24
Dry Cell, Some Characteristics of the Modern—D. L. Ordway....341
Ductile Tungsten and Molybdenum—C. G. Fink....229
Election, Report of the Tellers.... 7
Electric Furnaces, A Study in Heavy Alternating Current Conductors for—K. C. Randall....139
Electric Steel Furnace, A New—A. L. Queneau....131
Electro-Analytical Methods, Comparison of Rapid.—1. The Determination of Copper—F. C. Frary, A. P. Peterson....295
Electrochemical Potentials and Electrical Conductivity of Aluminium-Calcium Alloys—J. M. Breckenridge....367
Electrochemistry, What It Is Accomplishing—J. W. Richards.... 75
Electrodes, Determinations of the Constants of Materials for Furnace—Carl Hering 151
Electrodes, Empirical Laws of Furnace—Carl Hering....171
Electrodeposition of Lead from Perchlorate Baths—F. C. Mathers....261

PAGE
Electrodeposition of Platinum—II—W. J. McCaughey and H. E. Patten 275
Electrolysis of Cuprous Solutions, The Conductivity and—M. deK. Thompson and E. R. Hamilton 287
Electrolysis, The Separation of Oil from Condenser Water by—H. M. Goodwin and R. Ellis 405
Electrolytic Preparation of Magnesium—S. A. Tucker and F. L. Jouard 249
Electrolytic Reduction of Nitric Acid—III—H. E. Patten and W. J. McCaughey 377
Electrolytic Winning and Refining of Metals, A New Method for—E. M. Chance 235
Ellis, R. and H. M. Goodwin—The Separation of Oil from Condenser Water by Electrolysis 405
Empirical Laws of Furnace Electrodes—Carl Hering 171
Fink, C. G.—Ductile Tungsten and Molybdenum 229
Fink, C. G.—*Discussion* ..... 233 *et seq.*
Finney, J. H.—Conservation and Utilization of Natural Sources of Power 55
Firth-Stirling Steel Company, Demmler, Pa 19
Foster, C. E.—A New Radiation Pyrometer 223
Foster, C. E.—*Discussion* ..... 227 *et seq.*
Frary, F. C. and A. P. Peterson—Comparison of Rapid Electro-Analytical Methods 295
Furnace, A New Electric Steel—A. L. Queneau 131
Furnace Electrodes, Determinations of the Constants of Materials for —Carl Hering 151
Furnace Electrodes, Empirical Laws of—Carl Hering 171
Furnace Progress, Induction—T. Rowlands 103
Furnaces, A Study in Heavy Alternating Current Conductors for Electric—K. C. Randall 139
Gas in Steel, The Presence and Influences of—P. L. T. Heroult 135
Geological Survey Testing Station, United States 2
Gilfett, H. W.—*Discussion* ..... 201 *et seq.*
Goldbaum, J. S.—*Discussion* 273
Goodwin, H. M. and R. Ellis—The Separation of Oil from Condenser Water by Electrolysis 405
Goodwin, H. M.—*Discussion* 423
Graphite Anode, A Rotating—J. W. Turrentine 303
Guests Registered at the Seventeenth General Meeting 31
Hamilton, E. R. and M. deK. Thompson—The Conductivity and Electrolysis of Cuprous Chloride Solutions 287
Hansen, C. A.—*Discussions* ..... 133 *et seq.*, 147 *et seq.*
Hering, Carl—Determinations of the Constants of Materials for Furnace Electrodes 151
Hering, Carl—Empirical Laws of Furnace Electrodes 171

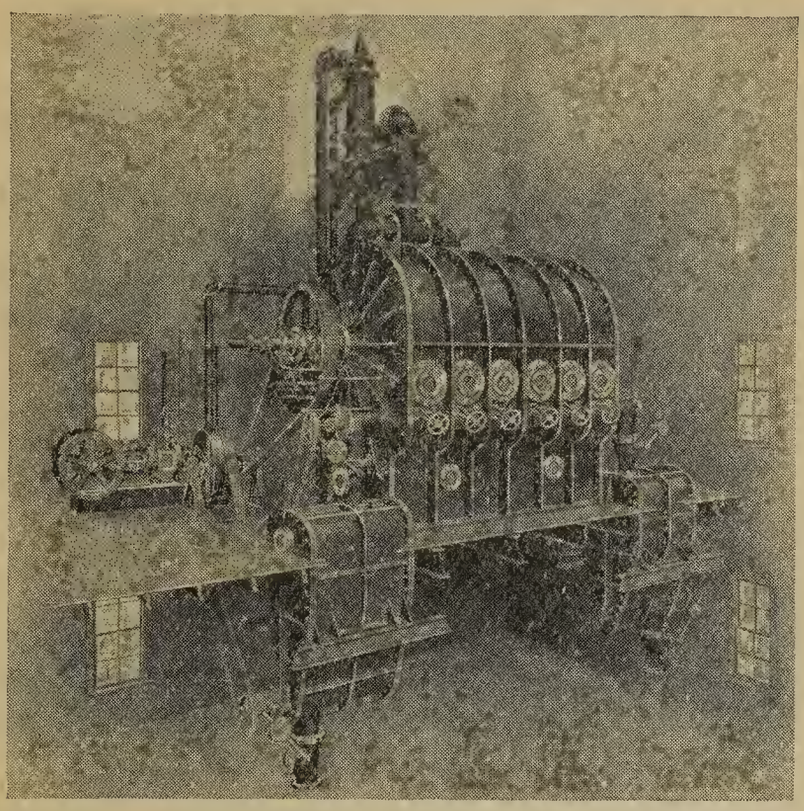
PAGE
Hering, Carl—*Discussions*.....134, 206 *et seq.*, 366
Heroult, P. L. T.—Presence and Influences of Gases in Steel.....135
Heroult, P. L. T.—*Discussion*.....137
Homestead Works: Carnegie Steel Company..... 20
Hooker, A. H.—*Discussion*.....325
Induction Furnace Progress—T. Rowlands.....103
Industry and Science—L. H. Baekeland..... 37
Influences of Gases in Steel, The Presence and—P. L. T. Heroult.....135
Isabella Furnaces, of Carnegie Steel Co..... 10
Jones & Laughlin Steel Co..... 11
Jouard, F. L. and S. A. Tucker—The Electrolytic Preparation of Magnesium 249
Kennelly, A. E.—*Discussion*.....199 *et seq.*
King, Mr.—*Discussion*.....233
Laws of Furnace Electrodes, Empirical—Carl Hering.....171
Lead from Perchlorate Baths, Electrodeposition of—F. C. Mathers....261
Lidbury, F. A.—*Discussion*.....207 *et seq.*
Lloyd, M. G.—*Discussion*.....147
Magnesium, The Electrolytic Preparation of—S. A. Tucker and F. L. Jouard 249
Mathers, F. C.—Electrodeposition of Lead from Perchlorate Baths....261
McCaughey, W. J. and H. E. Patten—Electrodeposition of Platinum. —II. 275
McCaughey, W. J. and H. E. Patten—On the Electrolytic Reduction of Nitric Acid—III.....377
McCormick, D. J.—Address of Welcome..... 21
Members and Guests Registered at the Seventeenth General Meeting... 30
Members Elected and Qualified..... 33
Metals, A New Method for the Electrolytic Winning and Refining of —E. M. Chance.....235
Method for the Electrolytic Winning and Refining of Metals—E. M. Chance 235
Moisture and of Solutions upon the Electric Conductivity of Soils, The Effect of—R. O. E. Davis.....391
Molybdenum, Ductile Tungsten and—C. G. Fink.....229
Morse, E. K.—Address of Welcome..... 3
Nernst Lamp Company, Pittsburgh, Pa..... 15
Nitric Acid, On the Electrolytic Reduction of—III—H. E. Patten and W. J. McCaughey.....377
Oil from Condenser Water by Electrolysis, The Separation of—H. M. Goodwin and R. Ellis.....405
On the Electrolytic Reduction of Nitric Acid—III—H. E. Patten and W. J. McCaughey.....377
Ordway, D. L.—Some Characteristics of the Modern Dry Cell.....341
Ordway, D. L.—*Discussion*.....366
Park Works of Crucible Steel Co. of America..... 10

PAGE
Parsons, L. A.—*Discussion* 234
Patten, H. E. and W. J. McCaughey—Electrodeposition of Platinum —II. 275
Patten, H. E. and W. J. McCaughey—On the Electrolytic Reduction of Nitric Acid—III 377
Patterson, R. L. and H. K. Richardson—The Townsend Cell 311
Pennsylvania Smelting Co., Carnegie, Pa 14
Perchlorate Baths, Electrodeposition of Lead from—F. C. Mathers 261
Peterson, A. P. and F. C. Frary—Comparison of Analytical Methods 295
Pittsburgh Reinforced Brazing and Machine Company 15
Plate Glass Company, Allegheny 16
Platinum, Electrodeposition of—II—W. J. McCaughey and H. E. Patten 275
Possibilities of Cheap Power in the Pittsburgh District—F. Crabtree 95
Potentials and Electrical Conductivity of Aluminium-Calcium Alloys —J. M. Breckenridge 367
Power, Conservation and Utilization of Natural Sources of—J. H. Finney 55
Power in the Pittsburgh District, Possibilities of Cheap—F. Crabtree 95
Preparation of Magnesium, The Electrolytic—S. A. Tucker and F. L. Jouard 249
Presence and Influences of Gases in Steel—P. L. T. Heroult 135
Presidential Address: Science and Industry—L. H. Baekeland 37
Proceedings of the Seventeenth General Meeting 1
Process for the Treating of Cobalt-Nickel Ores—C. C. Cito 239
Progress, Induction Furnace—T. Rowlands 103
Pyrometer, A New Radiation—C. E. Foster 223
Queneau, A. L.—A New Electric Steel Furnace 131
Queneau, A. L.—*Discussion* ..... 133 *et seq.*, 210 *et seq.*
Radiation Pyrometer, A New—C. E. Foster 223
Randall, K. C.—A Study in Heavy Alternating Current Conductors for Electric Furnaces 139
Randall, K. C.—*Discussion* 150
Reduction of Nitric Acid, On the Electrolytic—III—H. E. Patten and W. J. McCaughey 377
Refining of Metals, A New Method for the Electrolytic Wining and— E. M. Chance 235
Report of Board of Directors, Annual 24
Report of Secretary, Annual 25
Report of the Tellers of Election 7
Report of the Treasurer, Annual 29
Richards, J. W.—What Electrochemistry is Accomplishing 75
Richards, J. W.—*Discussions* ..... 208 *et seq.*, 228, 233, 272, 339 *et seq.*
Richardson, H. K. and R. L. Patterson—The Townsend Cell 311
Rotating Graphite Anode—J. W. Turrentine 303
Rowlands, T.—Induction Furnace Progress 103

PAGE
Science and Industry—L. H. Baekeland....37
Scott, C. F.—Address....5
Secretary, Annual Report of....25
Separation of Oil from Condenser Water by Electrolysis—H. M. Goodwin and R. Ellis....405
Soils, The Effect of Moisture and of Solutions Upon the Electric Conductivity of—R. O. E. Davis....391
Some Characteristics of the Modern Dry Cell—D. L. Ordway....341
Sources of Power, Conservation and Utilization of Natural—J. H. Finney....55
Steel Furnace, A New Electric—A. L. Queneau....131
Steel, The Presence and Influences of Gases in—P. L. T. Heroult....135
Study in Heavy Alternating Current Conductors for Electric Furnaces—K. C. Randall....139
Tellers of Election, Report of the....7
The Conductivity and Electrolysis of Cuprous Chloride Solutions—M. deK. Thompson and E. R. Hamilton....287
The Conservation and Utilization of Natural Sources of Power—J. H. Finney....55
The Effect of Moisture and of Solutions Upon the Electric Conductivity of Soils—R. O. E. Davis....391
The Electrodeposition of Platinum—II—W. J. McCaughey and H. E. Patten....275
The Electrolytic Preparation of Magnesium—S. A. Tucker and F. L. Jouard....249
The Presence and Influences of Gases in Steel—P. L. T. Heroult....135
The Separation of Oil from Condenser Water by Electrolysis—H. M. Goodwin and R. Ellis....405
The Townsend Cell; Its Behavior Under Various Densities—H. K. Richardson and R. L. Patterson....311
The Whiting Electrolytic Cell—J. Whiting....327
Thompson, M. deK. and E. R. Hamilton—The Conductivity and Electrolysis of Cuprous Chlorine Solutions....287
Townsend Cell; Its Behavior Under Various Densities—H. K. Richardson and R. L. Patterson....311
Treasurer, Annual Report of....29
Tucker, S. A. and F. L. Jouard—The Electrolytic Preparation of Magnesium....249
Tungsten and Molybdenum, Ductile—C. G. Fink....229
Turrentine, J. W.—A Rotating Graphite Anode....303
Utilization of Natural Sources of Power, Conservation and—J. H. Finney....55
Universal Portland Cement Company, Universal, Pa....14
Walker, W. H.—*Discussion*....423
Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa....17

PAGE
Westinghouse Machine Company, East Pittsburgh, Pa..... 18
What Electrochemistry is Accomplishing—J. W. Richards..... 75
Whiting Electrolytic Cell—J. Whiting.....327
Whiting, J.—The Whiting Electrolytic Cell.....327
Whiting, J.—*Discussion*.....338 *et seq.*
Winning and Refining of Metals, A New Method for the Electrolytic
—E. M. Chance.....235

Vacuum Drying Apparatus



Cut shows our Vacuum Rotary Drum Dryer, the most efficient dryer built for liquids. Note that chamber is cast in one piece and made of air furnace iron. MAINTAINS HIGHER VACUUM, THUS MORE EFFICIENT.

We Build Dryers for any Material and Capacity

Vacuum Rotary Drum
Vacuum Shelf
Vacuum Rotary
Non-Vacuum Rotary
Evaporators
Condensers
Pumps, Etc.

Write us your requirements

Rapid Drying and Evaporating at Low Temperature

Castings

NIGHT SCENE SHOWING OUR PLANT

Any size up to 200 tons in weight. Gray Iron, Semi-Steel and Air Furnace.

Chemical and Caustic Castings a Specialty

Have well equipped chemical and physical testing laboratory. Over 200 ton traveling crane capacity operated by Niagara Falls power.

Buffalo Foundry & Machine Co.

BUFFALO, N.Y.

There is more Graphite made every year in the Electric Furnaces of Niagara than is mined in the United States

ALL OF IT IS

ACHESON-GRAPHITE

The statement is significant and impressive. It indicates the world appreciates the fact that Acheson-Graphite is far superior to natural graphite for every purpose.

It is made in the form of Electrodes for Electrochemical and Metallurgical processes, and as a powder for Dry Cell Filler, Paint Pigment, Powder Glazing, Lead Pencils, Firearms Lubrication, General Lubrication, Electrotypers' Moulding and Polishing Leads. We also make a very superior line of Gredag lubricants for gear, cup and general use.

When Acheson-Graphite comes from the Electric Furnace there is no refining or purification necessary. Its quality does not depend upon difficult and unsuccessful after-treatment. So carefully is the supply of raw material selected and the furnace operation governed that each grade of graphite made by us is uniform in quality and the best of its class in its respective field of application.

When you buy graphite for any purpose, see that you get Acheson-Graphite—the Graphite of Certainty.

Ask for our Miniature Catalog 4022

International Acheson Graphite Co.

NIAGARA FALLS, N. Y.

ACHESON TRADE ELECTRIC FURNACE MARK GRAPHITE

Reg. U. S. Pat. Off.

New York Branch, Room 511 West St. Building, 90 West St.
Chicago Branch, 457 Monadnock Block
Pittsburgh Branch, 311 Penn Building
San Francisco, Fred Ward & Son
Crosier, Stephens & Co., Newcastle-on-Tyne, England
J. M. Currie, Havre, France
Georg A. Anthony, Hamburg 8 (Germany), Dovenhof 120

OXONE PRESSURE GENERATOR

For Portable Outfits of
Oxy=Acetylene Blowpipes
Oxy=Acetylene or
Oxy=Hydrogen Light
For Calorimeter Work, Etc.

Generates 100 per cent. pure Oxygen under any required pressure; works automatically

THE ROESSLER & HASSLACHER CHEMICAL CO.

100 WILLIAM STREET, NEW YORK

OXYGEN

FOR COMBUSTIONS AND CALORIMETER WORK

in mining and scientifical laboratories, is that obtained from

OXONE

Our OXONE GENERATORS, small and large size, yield a steady stream of ***100 Per Cent. Pure*** Oxygen gas.

Oxone produces the gas in situ upon contact with water, similar to the generation of acetylene by calcium carbide, rendering the work independent from the inconveniences adherent to impure tank oxygen.

PROF. IRA REMSEN in "An Introduction to the Study of Chemistry," in giving space to Oxone says: ***"When it is treated with water, oxygen is at once given off. This is the simplest way to make oxygen."***

VIRGIL COBLENTZ, Professor, Columbia University, Department Pharmacy, Member of the Committee of Revision of the U. S. Pharmacopœia, reports on the purity of Oxone—Oxygen as follows: ***"This is to certify that I have made a number of analyses of Oxygen prepared by means of the Oxone generator, from different Oxone cartridges, and find the dried gas to be absolutely free from all foreign gases, that is it consists of PURE OXYGEN. As given off from the wash-bottle, the gas contains a slight percentage of moisture."***

THE ROESSLER & HASSLACHER CHEMICAL COMPANY · NEW YORK · CHEMISTS · TRADE MARK

The Roessler & Hasslacher Chemical Co.
100 William Street, New York

PLATINUM

FOR ALL PURPOSES

Crucibles, Dishes, Triangles, Cones, Cylinder Cathodes of Perforated Sheet or Platinum Gauze.

Salts and Solutions of the Platinum Group of Metals. All Forms of Special Apparatus made to Specifications

ALL PLATINUM WARE
OF
BAKER QUALITY

SCRAP PURCHASED
WRITE FOR CATALOGUE

C. O. BAKER, Pres. C. W. BAKER, Vice Pres.

BAKER & CO., Inc.

New York Office,
30 Church Street

Newark, N. J.

WESTON *Alternating Current Switchboard*

Ammeters and Voltmeters

will be found vastly superior in accuracy, durability, workmanship and finish to any other instrument intended for the same service.

They are **Absolutely Dead Beat,** and **Extremely Sensitive.**

Their indications are **Practically Independent of Frequency** and also of **Wave Form.**

They are **Practically Free From Temperature Error.**

They require **Extremely Little Power to Operate Them, and They Are Very Low in Price.**

WESTON *Portable Alternating Current*

Ammeters, Milli-ammeters and Voltmeters

possess the same excellent characteristics.

The performance of all these instruments will be a revelation to users of alternating current apparatus.

WESTON *Eclipse Direct Current Switchboard*

Ammeters, Milli-ammeters and Voltmeters

are of the "soft-iron" or Electro-magnetic type; but they possess so many novel and valuable characteristics as to practically constitute a new type of instrument.

They are **exceedingly cheap,** but are remarkably accurate and well made, and nicely finished instruments, and are admirably adapted for general use in small plants, where cost is frequently an important consideration.

Correspondence concerning these new Weston instruments is solicited by

Weston Electrical Instrument Co.

Waverly Park NEWARK, N. J., U. S. A.

NEW YORK OFFICE, 114 Liberty Street

LONDON BRANCH: Audrey House, Ely Place, Holborn. PARIS, FRANCE: E. H. Cadiot, 12 Rue St. Georges. BERLIN: Weston Instrument Co., Ltd., Schoneberg, Geneststr. 5

Electrical Measuring Instruments

Portable and Switchboard

Direct and Alternating Current

Type P—Wattmeter for alternating current and direct current

G-E Direct Current Instruments are of the permanent magnet D'Arsonoal construction.

G-E Alternating Current Instruments are of the dynamometer and enclosed coil type.

G-E Instruments are magnetically shielded and needles are dead beat.

G-E Instruments are individually tested and calibrated in our own laboratories.

Type D. P.—Voltmeter for direct current

Descriptive bulletins will be sent on request

General Electric Company

Largest Electrical Manufacturer in the World

Principal Office
SCHENECTADY, N. Y.

Sales Offices
in all large cities

CHEMICALLY PURE

Laboratory Reagents

CHEMICALLY PURE ACIDS

Hydrochloric Acid, sp. gr., 1.19 **Nitric Acid, sp. gr., 1.42**
Sulphuric Acid, sp. gr., 1.84 **Acetic Acid, 99.5%**

AMMONIA WATER, Sp. Gr., 0.90

We manufacture and carry in stock a full line of Chemically Pure Analytical Reagents. These reagents do not require preliminary testing, and the results obtained by their use are accurate.

Our products will be furnished by the leading supply houses if B. & A. Chemicals are specified on orders.

The Baker & Adamson Chemical Co.

List Furnished on Request EASTON, PA.

CHAS. GRAHAM CHEMICAL POTTERY WORKS

986 Metropolitan Avenue BROOKLYN, NEW YORK

Manufacturers of all Kinds of

Stoneware Apparatus

—for—

CHEMICAL *and* ELECTROCHEMICAL INDUSTRIES

EUGENE A. BYRNES, PH.D
Ex Principal Examiner U. S. Patent Office

CLINTON PAUL TOWNSEND
Ex-Examiner of Electrochemistry

JOHN H. BRICKENSTEIN, Ex-Member Board of Examiners in Chief

Byrnes, Townsend & Brickenstein

PATENT LAWYERS

Domestic and Foreign Patents. Experts in Electricity, Metallurgy, Chemistry, Electrochemistry

National Union Building, 918 F St.

Rooms, 56-61 ***WASHINGTON, D. C.***

PLATINUM IN ANY DESIRED FORM FOR . .

Chemical, Electrical and Metallurgical Purposes

PLATINUM SCRAP PURCHASED OR
EXCHANGED FOR NEW WARE

J. Bishop and Company Platinum Works

Catalogue upon Request **MALVERN, PENNA.**

VOLUMES I, II, III, IV, V, VI, VII, VIII, IX, X
XI, XII, XIII, XIV, XV, XVI and XVII

Transactions
of the
American Electrochemical Society

Price, bound in cloth, $3.00 each. (Vol. III, $6.00)

Complete set, $40.50
(Vol. III, double price—nearly out of print).

To Colleges, Libraries, Societies and Journals, $2.00 each. (Vol. III, $4.00)
Complete set, $32.40

Only a limited number of first volumes on hand
Price will shortly be doubled on the early volumes, which are nearly out of print.

PROF. J. W. RICHARDS, Secretary
Lehigh University :: South Bethlehem, Pa.

Committee on Advertisements
American Electrochemical Society

W. S. LANDIS, *Chairman*
SOUTH BETHLEHEM, PA.

Members of the A. E. S. are earnestly requested to call the attention of advertisers to this excellent opportunity for securing new business among representative houses at a nominal expense.

Manufacturers of machinery, scientific instruments, appliances, materials, publishers and all other firms having business relations with the electrochemical industry, colleges and universities of the United States, will find the Transactions of this Society an excellent advertising medium.

The Transactions of the American Electrochemical Society are published in two octavo volumes each year, edition 2250, and circulate throughout the world.

Advertisements are accepted, inserted at the end of the volume, at the following prices:

One page,	. . . . .	$20.00 per insertion.
½ "	. . . . .	12.50 " "
¼ "	. . . . .	7.50 " "

Smaller, $5.00 per inch, per insertion.

Above prices are *Net Prices;* one copy of the cloth bound volume will be sent to each advertiser of ¼ page or over.

Address communications, copy, cuts, etc., to The American Electrochemical Society, South Bethlehem, Pa.

W. S. LANDIS,

Chairman Committee on Advertisements
American Electrochemical Society,

SOUTH BETHLEHEM, PA.

PE---CAL